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WIND-TUNNEL TESTS OF SPOILERS ON TAIL SURFACES

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE RESTRICTED REPORT

WIND-TUNNEL TESTS OF SPOILERS ON TAIL SURFACES

By Robert B. Liddell

SUMMARY

Wind-tunnel tests have been made in two-dimensional and three-dimensional flow to investigate the aerodynamic characteristics of spoilers on tail surfaces for low-speed flight.

The test results indicated that spoilers on tail surfaces showed little possibility of replacing conventional control surfaces. Spoilers might be used as auxiliary aids to conventional control surfaces if a number of the disadvantages that they present can be remedied or tolerated. These disadvantages consisted principally of high drag, erratic action, and an adverse effect on normal control-surface hinge moments.

A spoiler on the forward portion of the tail surface, used alone or in conjunction with the conventional control surface, gave unsatisfactory results because of its erratic effect throughout the angle-of-attack range. Spoilers generally should be located on the rear portion of the tail surface, but an auxiliary forward spoiler might be advantageous in depressing the tail in the landing maneuver. A forward auxiliary spoiler should be located on the opposite side of the tail surface from the rear spoiler, since two spoilers on the same side of the tail surface tend to cancel the effects obtained by the use of either spoiler alone.

INTRODUCTION

A number of modern airplanes have encountered difficulty in landing because of inadequate elevator control. Very large control deflections are required

for landing because of the marked increase in longitudinal stability that results from the proximity of the ground. The large elevator deflections required to attain the landing attitude cause the mechanical advantage of the control system to be low and the elevator hinge-moment coefficients to be high. These two factors result in high stick forces at both high and low speeds. Often the control forces necessary to trim the asymmetric yawing moments on single-engine airplanes with single-rotating propellers and on multiengine airplanes with asymmetric power are also excessive. In many cases the rudder effectiveness is insufficient even if the control forces are small.

It has been suggested that spoilers might be used as supplementary or auxiliary controls to reduce some of the control difficulties just mentioned. Tests have consequently been made at various times in the Langley 7- by 10-foot tunnel of spoiler-elevator controls on three complete airplane models. An NACA 0009 airfoil with various spoilers and combinations of spoilers also was tested in two-dimensional flow in the Langley 4- by 6-foot vertical tunnel.

The purpose of the present report is to collect, summarize, and analyze the data that have been obtained on the application of spoilers to tail surfaces for the critical control condition at low speed.

SYMBOLS AND CORRECTIONS

Symbols used for tests in two-dimensional flow are as follows:

c_l	airfoil section lift coefficient	$\left(\frac{l}{qc}\right)$
cd_o	airfoil section profile-drag coefficient	$\left(\frac{c_{d_o}}{qc}\right)$
c_m	airfoil section pitching-moment coefficient	$\left(\frac{m}{qc^2}\right)$
c_{h_f}	flap section hinge-moment coefficient	$\left(\frac{h_f}{qc_f^2}\right)$
c_{h_t}	tab section hinge-moment coefficient	$\left(\frac{h_t}{qc_t^2}\right)$

l	airfoil section lift, pounds
d_o	airfoil section profile drag, pounds
m	airfoil section pitching moment, foot-pounds
h_f	flap section hinge moment, foot-pounds
h_t	tab section hinge moment, foot-pounds
q	dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho v^2\right)$
c	chord of airfoil section (2 ft)
c_f	flap chord, feet
c_t	tab chord, feet
α_o	angle of attack for infinite aspect ratio
δ_f	deflection of flap with respect to airfoil, degrees; positive when trailing edge is moved down
δ_t	deflection of tab with respect to flap, degrees; positive when trailing edge is moved down
ρ	mass density of air, slug per cubic foot
V	air velocity, feet per second

Symbols used for tests in three-dimensional flow are as follows:

C_L	lift coefficient $\left(\frac{L}{qS}\right)$
C_{DR}	resultant-drag coefficient $\left(\frac{D}{qS}\right)$
C_m	pitching-moment coefficient $\left(\frac{M}{qSc}\right)$
C_{h_e}	elevator hinge-moment coefficient $\left(\frac{H_e}{qb_e \bar{c}_e^2}\right)$
D	resultant drag, pounds
L	lift, pounds
M	pitching moment, foot-pounds

H_e	elevator hinge moment, foot-pounds
q	dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho v^2\right)$
S	wing area (9.44 sq ft for model A; 6.65 sq ft for model B)
c'	wing mean aerodynamic chord (1.36 ft for model A; 1.07 ft for model B)
b_e	span of elevator (2.50 ft for model A; 2.79 ft for model B)
$\overline{c_e}$	root-mean-square chord of elevator behind hinge line (0.199 ft for model A; 0.160 ft for model B)
α	angle of attack of fuselage reference line, degrees
δ_e	elevator deflection, degrees; positive when trailing edge is moved down
δ_r	deflection of rudder with respect to fin, degrees; positive when trailing edge is moved to left
δ_f	flap deflection, degrees; positive when trailing edge is moved down
i_t	angle of stabilizer with respect to fuselage reference line, degrees; positive when trailing edge is moved down
ρ	mass density of air, slug per cubic foot
V	air velocity, feet per second
ψ	angle of yaw
$c_{t_{av}}$	average chord of horizontal tail (0.637 ft for model A)
c_t	chord of horizontal tail at any point along span
c_s	height or chord of spoiler; expressed in fraction of $c_{t_{av}}$ for model A and c_t for model B
δ_s	projection of spoiler measured perpendicularly from top edge of spoiler to surface of tail; positive when spoiler projects from lower surface and negative when spoiler projects from upper surface; expressed in fraction of $c_{t_{av}}$ for model A and c_t for model B

Subscripts:

F forward

R rear

Tunnel corrections were applied to the airfoil section lift coefficient c_l as explained in reference 1. No corrections were applied to the airfoil section pitching-moment coefficient c_m or to the airfoil section profile-drag coefficient c_{d_0} , although the values of c_{d_0} presented may be too large as explained in reference 1. The angle of attack was not corrected, but this correction would be quite small.

APPARATUS, MODELS, AND TESTS

Two-Dimensional Flow

The section data presented herein were obtained from tests made in the Langley 4- by 6-foot vertical tunnel (reference 2) modified as discussed in reference 3. The 2-foot-chord by 4-foot-span model was made of laminated mahogany and conformed to the NACA 0009 profile. The airfoil profile with spoilers in forward and rear locations is shown in figure 1. The model had an enclosed hinge-moment balance for measuring the hinge moments of the 0.30c plain flap. The spoilers were made of sheet steel 1/32 inch thick, had spans of 4 feet, and were projected 0.01c, 0.03c, 0.06c, and 0.09c at the forward location and 0.01c, 0.025c, 0.05c, 0.10c, and 0.15c at the rear location. The spoilers were screwed to the model at right angles to the surface, and strips of cellulose "scotch" tape were used to prevent air flow under the spoilers.

The tests were made at an average dynamic pressure of 15 pounds per square foot, which corresponds to a velocity of 76 miles per hour under standard conditions. The test Reynolds number was 1,430,000, and the effective Reynolds number was 2,765,000 based on a turbulence factor of 1.93 for the Langley 4- by 6-foot vertical tunnel. A résumé of the tests in two-dimensional flow is given in table I.

Three-Dimensional Flow

Three low-wing complete airplane models were tested in the Langley 7- by 10-foot tunnel, which is described in reference 1. Tests were made of a model of a single-engine fighter airplane with single-rotating propeller, which is referred to herein as "model A." Other tests were made of a single-engine bomber-torpedo model with dual-rotating propeller, which is referred to herein as "model B." A few tests were made of a third complete model of a typical fighter airplane to find the effects of elevator nose gap on the characteristics of a tail with a spoiler.

The ground was simulated by a flat wooden board extending completely across the tunnel and several feet ahead of and behind the model. A complete description of this ground board is given in reference 4. The ground board was adjusted so that it was almost tangent to the front wheels of the landing gear at an angle of attack of 0° - the wheels actually never made contact with the ground board.

Model A.- A three-view drawing of model A is shown in figure 2. When the model was set at the angle of attack for maximum lift coefficient (13°), the landing gear was about $1\frac{1}{2}$ inches above the ground board.

The spoilers had spans of 73 percent of the horizontal-tail span and were made in two sections, which were mounted symmetrically on each half of the horizontal tail. Single spoilers with chords of 0.06, 0.09, 0.15, and 0.25 of the average tail chord were tested. For most of the tests, the spoilers were mounted parallel to the trailing edge of the tail at 67.7 percent of the average tail chord (fig. 3(a)). A few tests were made with combinations of two spoilers mounted as shown in figure 3(b).

All tests of model A were made at a dynamic pressure of 4.09 pounds per square foot, which corresponds to a velocity of about 40 miles per hour and to a test Reynolds number of about 497,000 based on a mean aerodynamic chord of the model wing of 16.32 inches. The effective Reynolds number was about 795,000 based on a turbulence factor of 1.6 for the Langley 7- by 10-foot tunnel. All tests were made with the propeller windmilling.

Tests were made with spoilers of several chords, for which the spoiler projection was equal to the chord. As a basis for comparison, tests were made with the model near the ground board, the split flaps neutral or deflected 45° , and elevator deflections (plain elevator with gap sealed) ranging from 0° to -45° . A few tests were made with a fixed-chord spoiler at projections that introduced a gap between the spoiler and the upper surface of the tail. Combinations of spoilers were also tested on the upper and the lower surfaces of the tail. A résumé of the tests of model A is given in table II.

Model B.— A three-view drawing of model B is shown in figure 4, and a diagram of the model mounted near the ground board is shown in figure 5. The horizontal tail (fig. 6(a)) was tested in the normal location or raised 4.0 inches as shown in figure 6(b). The vertical tail was removed for all tests with the raised horizontal tail, since data not presented show that the vertical tail has no effect on the longitudinal stability characteristics.

The dimensions and location of the spoilers tested on the horizontal tail are shown in figure 6(a). Since the tail thickness at the station at which the spoilers were located was 0.10 of the tail chord, this thickness determined the maximum spoiler projection that could be retracted into the tail perpendicular to the chord line. In addition to the spoilers of maximum height, spoilers of $0.01c_t$, $0.025c_t$, and $0.05c_t$ were tested. The spoilers were constructed of steel plate $1/32$ inch thick and were fastened to the tail surface by means of small metal angles.

All tests of model B were made at a dynamic pressure of 16.37 pounds per square foot, which corresponds to a velocity of about 80 miles per hour and to a test Reynolds number of about 800,000 based on the wing mean aerodynamic chord of 12.81 inches. The effective Reynolds number was about 1,280,000 based on the turbulence factor of 1.6. All tests were made with the propeller windmilling and with the model in the landing configuration, which is defined as follows:

Inboard-flap deflection, δ_{f_i} , deg.	50
Outboard-flap (balanced split) deflection, δ_{f_o} , deg.	50
Cowl-flaps deflection, δ_{f_c} , deg.	25
Landing gear and slats	Extended

Tests were made with elevator alone and with spoiler projections of $0.01c_t$, $0.025c_t$, $0.05c_t$, and $0.10c_t$ for the horizontal tail in its normal location. Elevator tests without a spoiler and with a spoiler projection of $0.10c_t$ were made for the horizontal tail in its raised location. A résumé of tests of model B is given in table III.

Elevator gap.- A drawing of the horizontal tail and a $0.008c_t$ spoiler on the model tested to find the effect of sealing the elevator gap is shown in figure 7. Four tests were made with the nose gap sealed or unsealed and with or without a spoiler.

Elevator deflection required to land.- Some data on the elevator deflection required to land were compiled for various fighter models tested in the Langley 7- by 10-foot tunnel. These models were tested near a ground board, and the data are presented in figure 8.

All of the data from tests in three-dimensional flow, except those for model A with flaps retracted, are uncorrected for tare due to the model support. No corrections for tunnel-wall effect have been applied, since reference 1 indicates that the tunnel correction for the ground-board test installation is negligible. All forces and moments for models A and B are given with respect to the wind axes of the models; center-of-gravity locations shown in figures 2 and 5 are used.

RESULTS AND DISCUSSION

Two-Dimensional Flow

The results of the tests in two-dimensional flow are given as airfoil aerodynamic section characteristics in figures 9 to 16. For the purpose of showing the effectiveness of the various arrangements, increments of section lift coefficient and flap section hinge-moment coefficient are plotted against flap deflection and spoiler projection in figures 17 to 26.

Flap alone.- The curves of figure 9 show the effect of flap deflection on the aerodynamic section characteristics of the plain airfoil. Increments of lift and hinge-moment coefficients produced by flap deflection

obtained from figure 9 for various angles of attack are presented in figure 17. These curves are a basis for the comparison of the effectiveness of various combinations of spoilers or of spoilers and flaps.

For the landing maneuver, a -30° deflection of a 0.30c flap is usually sufficient for a conventional fighter airplane. The angle of attack of the tail is approximately 8° in landing. A flap deflection of -30° was not tested but, for a flap deflection of 30° and an angle of attack of -8° (reference 5), which can be used since the airfoil is symmetrical, the data of figure 17 indicate that the increment of airfoil section lift coefficient would be about -1.07. Any satisfactory arrangement of spoiler or of spoiler and flap therefore should develop about this increment of airfoil section lift coefficient.

Rear spoiler alone.- A rear spoiler alone on the upper or lower surface appears to be usable as a control device (figs. 10 and 13) except for its ineffectiveness in producing changes in lift at low spoiler projections. This ineffectiveness apparently occurs at all angles of attack within the range investigated but is less marked at large positive angles of attack for upper-surface spoilers. The ineffectiveness of this spoiler in increasing lift might be a distinct disadvantage during high-speed maneuvering. The data of reference 6, however, indicate that rear spoilers used for lateral control at high speed on wings show no objectionable lag in effectiveness with projection. The present data thus are not conclusive for high-speed flight.

The slope of the curves of lift-coefficient increment for the rear spoiler (fig. 13) is similar to that for the plain flap (fig. 17). Except for the range in which the spoiler is ineffective, a spoiler projection of about 0.06c corresponds to a flap deflection of about 10° .

A serious disadvantage of the rear spoiler alone is its excessively large drag at large projections. It is estimated that, if a high-speed fighter airplane required an elevator deflection of 10° in a tight turn, the drag of an equally effective spoiler would be about 18 times the drag of the elevator. This high drag would produce a stabilizing moment unfavorable to depressing the tail in the landing maneuver.

Forward spoiler alone.- With the spoiler at the 0.15c location, the values of the lift-coefficient increment vary erratically with changes in spoiler height and angle of attack (figs. 11 and 19). With the spoiler on the upper surface and the model at a positive angle of attack, the lift-coefficient increment increases negatively with an increase in spoiler projection; with the spoiler on the upper surface and the model at a negative angle of attack, the increment increases positively. With the spoiler on either surface and the model at a low angle of attack, the results show an uncertain variation in the increments of lift coefficient and flap hinge-moment coefficient. The forward spoiler caused all the aerodynamic coefficients to vary erratically throughout the lift range.

Forward spoiler and flap.- In an effort to study the performance of the model with the forward spoiler and the flap operating simultaneously, the data of figure 12 were replotted in figures 20 and 21 with a spoiler projecting 0.05c for every 10° of flap deflection. A comparison of figures 20 and 21 with figure 19 indicates that deflecting the flap in conjunction with the spoiler increases the negative value of Δc_l at a positive angle of attack; but, as with the forward spoiler alone, the results are uncertain at zero and negative angles of attack.

An improvement in performance seemed possible by use of a delayed-action spoiler. Such a condition was investigated with the spoiler remaining within the airfoil contour until the flap was deflected -5° and then projecting 0.05c for every 10° of flap deflection (fig. 22). This arrangement proved only slightly better than that in which the flap and spoiler operated simultaneously, and the results are still uncertain at zero and negative angles of attack.

The forward spoiler on the upper surface was tested with the tab deflected $\pm 15^\circ$ and the flap neutral, and the results are presented in figure 13. Although no analysis of these data was made, it is obvious that this combination has the same characteristics as the forward spoiler and flap combination.

The forward spoiler alone or in combination with a flap or tab appears to be unsatisfactory, because of the difference in the effect of the spoiler at positive and

negative angles of attack. The flap hinge-moment coefficients are also very erratic when the forward spoiler is projected (figs. 11 to 13).

Combination of forward and rear spoilers on upper surface.— From the data of figure 14, the curves of figures 23 and 24 were plotted to show the effect of two systems of operation of double spoilers on the upper surface of the airfoil. With the two spoilers operating simultaneously (fig. 23), the effect on lift at an angle of attack of 8° at small spoiler projections is of the same magnitude as with the rear spoiler alone (fig. 18). At angles of attack of 0° and -8° , the two spoilers tend to cancel the effect produced by either one acting alone. With the delayed-action system (fig. 24), the results at all angles of attack are too erratic for this system to be used as a control device. The section data for the double-spoiler arrangements show the same erratic characteristics (fig. 14) as noted for the forward spoiler alone.

Combinations of spoilers on upper and lower surfaces.— Data for various combinations of rear spoiler on the lower surface and forward spoiler on the upper surface are given in figure 15. At any particular constant value of forward-spoiler height and angle of attack, projecting the rear spoiler increases the lift positively. In order to apply the data of figure 15 directly to the landing problem, it therefore is necessary to think of the combination as a forward spoiler on the lower surface and a rear spoiler on the upper surface with the signs of the angle of attack and the lift coefficient reversed. This assumption is valid because the airfoil is symmetrical and the flap and tab were not deflected.

Data are presented for a rear spoiler on the upper surface and a forward spoiler on the lower surface in figure 16. These data are a replot of some of the curves of figure 15 with the signs reversed to give a negative increment of lift coefficient with an increase in spoiler height and with a constant proportional variation in the heights of the forward and rear spoilers.

Increments of airfoil section lift coefficient as a function of spoiler projection are presented in figures 25 and 26 for

combinations of forward and rear spoiler. The combination spoilers have very high effectiveness for positive angles of attack and appear to be satisfactory for depressing the tail of an airplane in the landing maneuver. The combination with a delayed-action forward spoiler (fig. 26) is more effective than the combination with spoilers acting simultaneously at an angle of attack of 0° but is less effective at an angle of attack of 8° . Even these combinations, which were very effective for the landing maneuver, could hardly be used alone as a pitch or yaw control device because of their erratic and adverse effects throughout the angle-of-attack range.

Complete Model A

Effect of elevator deflection.- The effect of elevator deflection on the aerodynamic characteristics of model A near the ground board is shown in figure 27. With the flaps either neutral or deflected, an elevator deflection of -30° is required to trim the model at maximum lift. As may be expected, the hinge-moment coefficients are high at the elevator deflection for trim. The stick forces, based on these hinge-moment coefficients, for an actual airplane in the landing maneuver would be high but not excessive.

Effect of spoiler projection.- The effect of spoiler projection on the aerodynamic characteristics of model A is shown in figure 28. In these tests the spoiler projections were equal to the spoiler chords. The data show that a spoiler chord of at least $0.15c_{tav}$ is required to trim the model near maximum lift with the flaps either neutral or deflected.

Effect of spoiler gap.- The effect of spoiler gap on the aerodynamic characteristics of model A with a spoiler of constant chord (spoiler on upper surface) is shown in figure 29. The maximum effectiveness is obtained when the spoiler projection is equal to the spoiler chord. The effectiveness decreases when the projection is greater than the chord; that is, when there is a gap between the surface of the tail and the lower edge of the spoiler. This loss in effectiveness increases with an increase in gap between the spoiler and tail.

Effect of spoiler combinations.- In an effort to increase the effectiveness of the spoilers, two combinations of spoilers having different chords were tested on model A and the results are shown in figure 30. With both spoilers on the upper surface, the effectiveness is less than the effectiveness of a $0.06c_{t_{av}}$ rear spoiler alone (fig. 28). This result is in agreement with the results of the section data previously discussed, which indicate that two spoilers on the same surface tend to cancel the effects of each other. With the forward spoiler on the lower surface and the rear spoiler on the upper surface, however, a quite effective combination is obtained and it is necessary to project the rear spoiler only $-0.09c_{t_{av}}$ and the forward spoiler only $-0.06c_{t_{av}}$ (fig. 30) to obtain the same effectiveness as for the $-0.15c_{t_{av}}$ rear spoiler alone (fig. 23). If spoilers were used in landing an airplane, the use of double spoilers rather than a rear spoiler alone would be advantageous, since a $0.15c_{t_{av}}$ rear spoiler might prove difficult to retract within a tail surface contour of normal thickness.

Comparison of elevators and spoilers.- The elevator deflections and the spoiler projections required to trim model A at any given lift coefficient are shown in figure 31. A 3-percent spoiler projection generally is equally as effective as an elevator deflection of 1° . Since the spoilers on this model spanned 78 percent of the tail span, this relative effectiveness is in very close agreement with the relative effectiveness of the spoiler-flap arrangement of the model in two-dimensional flow.

Complete Model B

The effects on the aerodynamic characteristics of various elevator deflections and spoiler projections with the horizontal tail of model B in both its normal and raised locations are shown in figures 32 to 34. In order to analyze the pertinent information provided by these data, the elevator deflection required to trim is plotted against the model angle of attack (fig. 35). The results (fig. 35) are presented for a forward center-of-gravity location of $0.14c$ for a stabilizer setting of -1.4° . The center-of-gravity location used in this analysis is the most forward, since it would be the

critical location in landing. A stabilizer setting of -1.4° is used since it has been estimated that this setting would be required for the elevator to have a desirably small positive deflection for a normal center-of-gravity location at high speed.

The elevator of model B was not sufficient to trim the model near the ground and thus spoilers were used to provide auxiliary negative lift near the ground.

Effect of tail location.- With the tail in the normal location (fig. 35), a 0.10c_t spoiler and an elevator deflection of 25° are required to attain the landing attitude. The curves of figure 35 show that, if a spoiler is linked so that it projects in proportion to the elevator deflection, the resulting combination gives satisfactory trim characteristics. With the 0.10c_t spoiler, the elevator deflection required to land is less with the raised tail than with the tail in the normal location. The reason for the larger elevator deflection required for the raised tail without spoilers seems to be an unexplained decrease in elevator effectiveness. The data also indicate that spoiler effectiveness decreases considerably as the elevator deflection is increased.

Effect of spoilers on stick force.- From the data of figures 32 to 34, the stick force required to trim model B near the ground has been estimated for a full-scale airplane and the results are presented in figure 36. The addition of a spoiler causes an unfavorable variation of stick force with angle of attack. The elevator overbalance, at large spoiler projections and elevator deflections, occurs because the spoiler in front of the elevator deflects the air so that the load on the portion of the elevator behind the hinge line is decreased. The elevator balance, which has been little affected by the spoiler, contributes its full influence and overbalance thus results. Spoilers used in conjunction with the elevator or rudder would not be desirable because of the erratic and overbalancing effect produced on the hinge moments of the conventional control surface.

Effect of spoiler combinations.- Model B was tested with various spoiler combinations in an attempt to determine their relative merits. The results of the tests (fig. 37) are quite erratic, probably because of

the nonuniform variation in downwash angle and dynamic pressure at the tail throughout the angle-of-attack range for model B. The average downwash angle throughout the model angle-of-attack range is about 6.5° . The large change in the slope of the pitching-moment curves thus occurs in the region of low angle of attack at the tail. The forward spoilers, as well as combination spoilers, generally cause a large unfavorable change in trim in the region in which the model angle of attack is low and the tail angle of attack is negative. The erratic and often adverse effect of forward spoilers at low and negative angles of attack is also evident in the section data previously discussed.

The combinations of forward spoilers on the lower surface and rear spoilers on the upper surface are effective at positive tail angles of attack but have the same disadvantages as all forward spoilers in that their effect is adverse at low and negative tail angles of attack. Spoilers on model B as well as model A showed little possibility of replacing conventional tail control surfaces on airplanes but might be used as auxiliary control devices if a number of the serious disadvantages that they present can be remedied or tolerated.

The reason the pitching-moment curve of model A (fig. 37) did not show an irregularity as did the pitching-moment curve of model B with combination spoilers is unknown, but the difference might be caused by the existence of a more regular flow field near the tail of model A.

Effect of elevator gap behind spoiler.— The data of figures 33 and 35 obtained in three-dimensional flow indicate that the effectiveness for a small spoiler projection is larger than section data indicate. This change in effectiveness for small spoiler projections was thought to be some function of the elevator gap. A few tests of a typical fighter model were therefore made to determine the effect of elevator gap on spoiler effectiveness. These tests were made with the model not in the presence of a ground board, but this condition should have little effect on the relative merits of the various arrangements tested. A $0.008c_t$ spoiler was used and the results show that a gap behind this small spoiler causes the spoiler to become very effective (fig. 36). The small spoiler causes a large

negative peak pressure near the gap, which induces a large air flow through the gap. The flow through the gap results in an upwash much the same as that obtained by deflecting an elevator upward. This increase in spoiler effectiveness by the use of an elevator gap has previously been reported (reference 7). If spoilers were used on airplane tail surfaces, it therefore would be a definite advantage to locate them just ahead of an unsealed gap or slot through the tail surface.

CONCLUSIONS

Spoilers have been tested at low speed on a model in two-dimensional flow and on the tail surfaces of three complete airplane models. The following conclusions were drawn from an analysis of the results of these tests:

1. Spoilers showed little possibility of replacing conventional tail control surfaces on airplanes but might be used as auxiliary control devices if a number of the serious disadvantages that they present can be remedied or tolerated. These disadvantages and problems, however, were quite serious and the widespread use of spoilers on tail surfaces does not appear likely.

2. Spoilers generally should be located at the rear portion of the tail surface. It might be advantageous, however, to locate an auxiliary spoiler forward on the lower surface of the horizontal tail in order to aid in depressing the tail in the landing maneuver. In flight, the use of this auxiliary spoiler, when spoilers alone are used for landing, might be necessary if the spoiler projection on the upper surface were limited to the airfoil thickness.

3. A forward spoiler alone or in conjunction with the conventional control surface gave unsatisfactory results because of its erratic action throughout the angle-of-attack range.

4. A forward auxiliary spoiler should be located on the opposite side of the tail surface from the rear spoiler, since two spoilers on the same side of the tail surface tended to cancel the effects obtained by the use of either spoiler alone.

5. A gap between the spoiler and tail surface resulted in a loss in spoiler effectiveness that increased with an increase in gap.

6. In flight the drag produced by a spoiler used to replace a conventional control surface would be many times as great as that of a conventional control surface. A tail drag of large magnitude would be a decided disadvantage.

7. The ineffectiveness for small spoiler projections might be eliminated by locating the spoiler just ahead of an unsealed gap or slot through the tail surface.

8. Spoilers used in conjunction with the elevator or rudder would not be desirable because of the erratic and overbalancing effect produced on the hinge moments of the conventional control surface.

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TABLE I.- RESUME OF TESTS IN TWO-DIMENSIONAL FLOW

Test	Forward-spoiler height (fraction c)	Rear spoiler		Flap deflection (deg)	Tab deflection (deg)	Figure
		Height (fraction c)	Surface			
1	None	0.01	Upper	0	0	16
2	0.01	.025	Upper	↓	↓	14(a), 16
3	↓	.025	Lower			15(a)
4		.05	Upper			14(a)
5		.05	Lower			15(a)
6		.10	Upper			14(a)
7		.10	Lower			15(a)
8		.15	Upper			14(a)
9		.15	Lower			15(a)
10		None	-----			11, 12(a)
11		↓	-----	10		12(a)
12			-----	-10		12(a)
13			-----	20	↓	12(a)
14			-----	-20		12(a)
15			-----	0		13(a)
16			-----	↓	15	15(b)
17	.03	0.05	Upper		-15	14(b), 16
18	↓	.05	Lower		0	15(b)
19		.10	Upper		↓	14(b)
20		.10	Lower			15(b)
21		.15	Upper			14(b)
22		.15	Lower			15(b)
23		None	-----			11, 12(b), 14(b), 15(b)
24		↓	-----	10		12(b)
25			-----	-10		12(b)
26			-----	20		12(b)
27			-----	-20		12(b)
28			-----	0		13(a)
29			-----	0	-15	13(b)

TABLE I.- RESUME OF TESTS IN TWO-DIMENSIONAL FLOW - Concluded

Test	Forward-spoiler height (fraction c)	Rear spoiler		Flap deflection (deg)	Tab deflection (deg)	Figure
		Height (fraction c)	Surface			
30	0.06	0.10	Upper	0	0	14(o), 16
31		.10	Lower	↓	↓	15(o)
32		.15	Upper	↓	↓	14(o)
33		.15	Lower	↓	↓	15(o)
34		None	-----	↓	↓	11, 12(c), 14(o), 15(c)
35		↓	-----	10	↓	12(o)
36		↓	-----	-10	↓	12(c)
37		↓	-----	20	↓	12(c)
38		↓	-----	-20	↓	12(c)
39		↓	-----	0	15	13(a)
40	.09	↓	-----	↓	-15	13(b)
41		0.10	Upper	↓	0	14(d)
42		.10	Lower	↓	↓	15(d)
43		.15	Upper	↓	↓	14(d), 16
44		.15	Lower	↓	↓	15(d)
45		None	-----	↓	↓	11, 12(d), 14(d), 15(d)
46		↓	-----	10	↓	12(d)
47		↓	-----	-10	↓	12(d)
48		↓	-----	20	↓	12(d)
49		↓	-----	-20	↓	12(d)
50	None	↓	-----	0	15	13(a)
51		↓	-----	↓	-15	13(b)
52		↓	-----	↓	15	13(a)
53		↓	-----	↓	-15	13(b)
54		↓	-----	↓	0	9, 10, 11, 16
55		↓	-----	-10	↓	9
56		↓	-----	-20	↓	9
57		↓	-----	10	↓	9
58		↓	-----	20	↓	19
59		0.025	Upper	0	↓	10
60	↓	.05	Upper	↓	↓	10
61		.10	Upper	↓	↓	10
62		.15	Upper	↓	↓	10

TABLE II.- RESUME OF TESTS OF MODEL A

[Three-dimensional flow; complete model; landing gear down; $\delta_r = 0^\circ$]

Test	δ_f (deg)	i_t (deg)	δ_e (deg)	c_s (fraction of $c_{t_{av}}$)	δ_s (fraction of $c_{t_{ev}}$)	Figure
1	0	2.25	0	None	None	27(a)
2	↓	↓	-10	↓	↓	27(a)
3	↓	↓	-15	↓	↓	27(a)
4	↓	↓	-30	↓	↓	27(a)
5	↓	↓	-45	↓	↓	27(a)
6	↓	↓	0	0.06	-0.06	28(a)
7	↓	↓	↓	.09	-.09	28(a)
8	↓	↓	↓	.15	-.15	28(a)
9	↓	↓	↓	.25	-.25	28(a)
10	45	2.00	↓	None	None	27(b), 28(b), 29
11	↓	↓	-10	↓	↓	27(b)
12	↓	↓	-15	↓	↓	27(b)
13	↓	↓	-30	↓	↓	27(b)
14	↓	↓	0	0.06	-0.06	25(b)
15	↓	↓	↓	.09	-.09	28(b), 29
16	↓	↓	↓	.15	-.15	28(b)
17	↓	↓	↓	.25	-.25	28(b)
18	↓	↓	↓	.09	-.15	29
19	↓	↓	↓	.09	-.21	29
20	↓	↓	↓	{ ^a .09 ^b .06}	{ ^a -.09 ^b -.06}	30
21	↓	↓	↓	{ ^a .09 ^b .06}	{ ^a -.09 ^b .06}	30

^aRear spoiler in combination.^bForward spoiler in combination.NATIONAL ADVISORY
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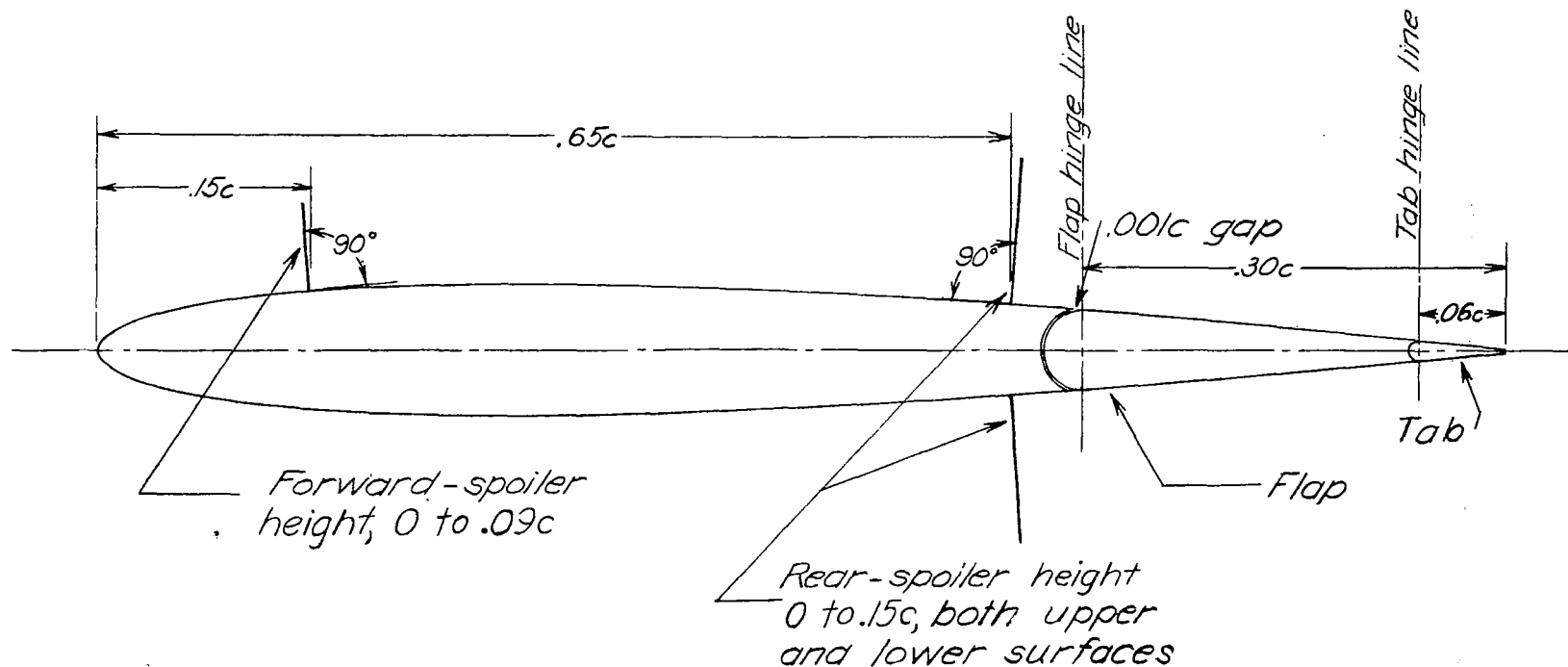


Figure 1.-NACA 0009 airfoil section showing size and location of flap, tab, and spoilers. Airfoil chord=2 feet.

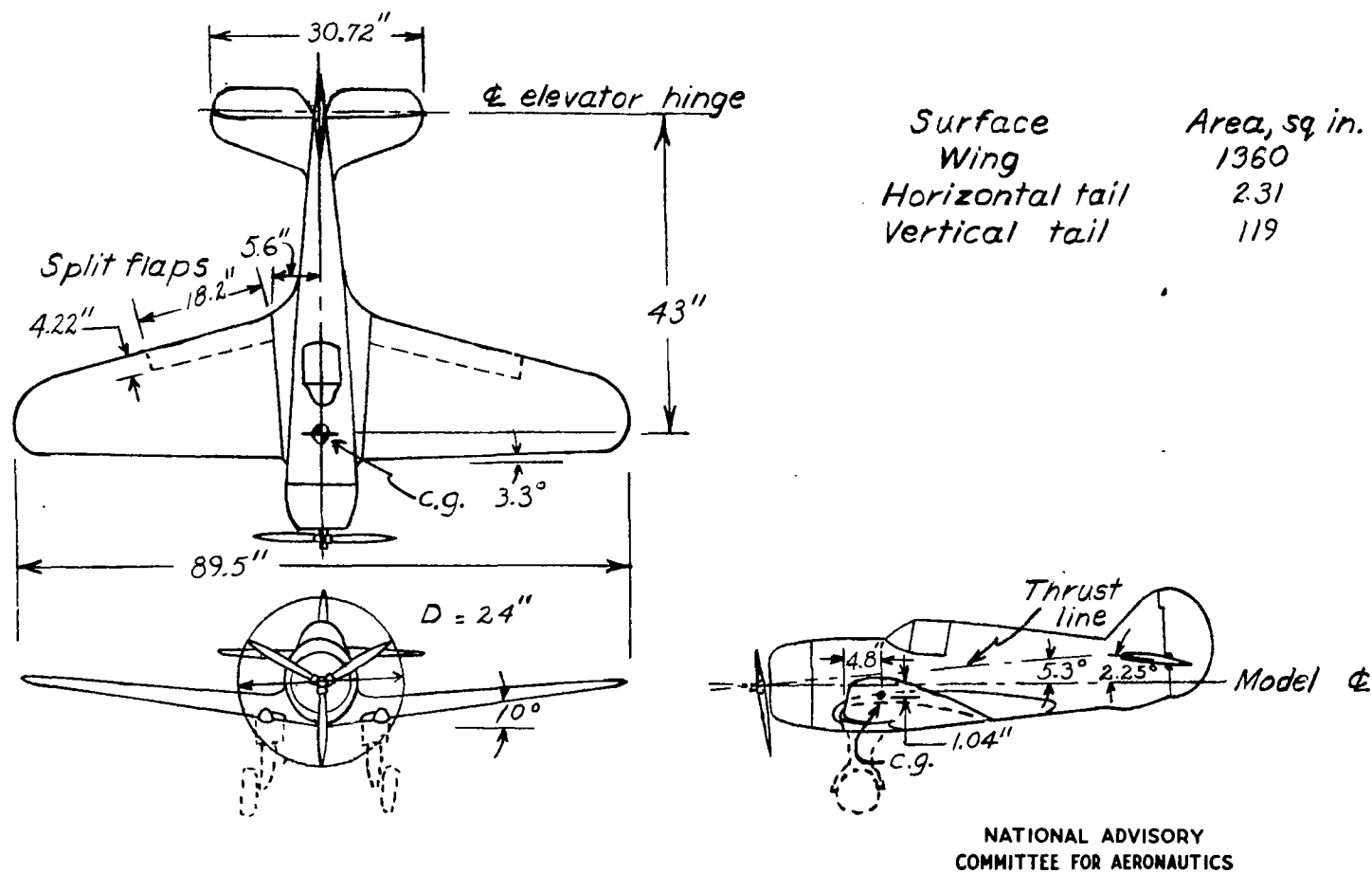
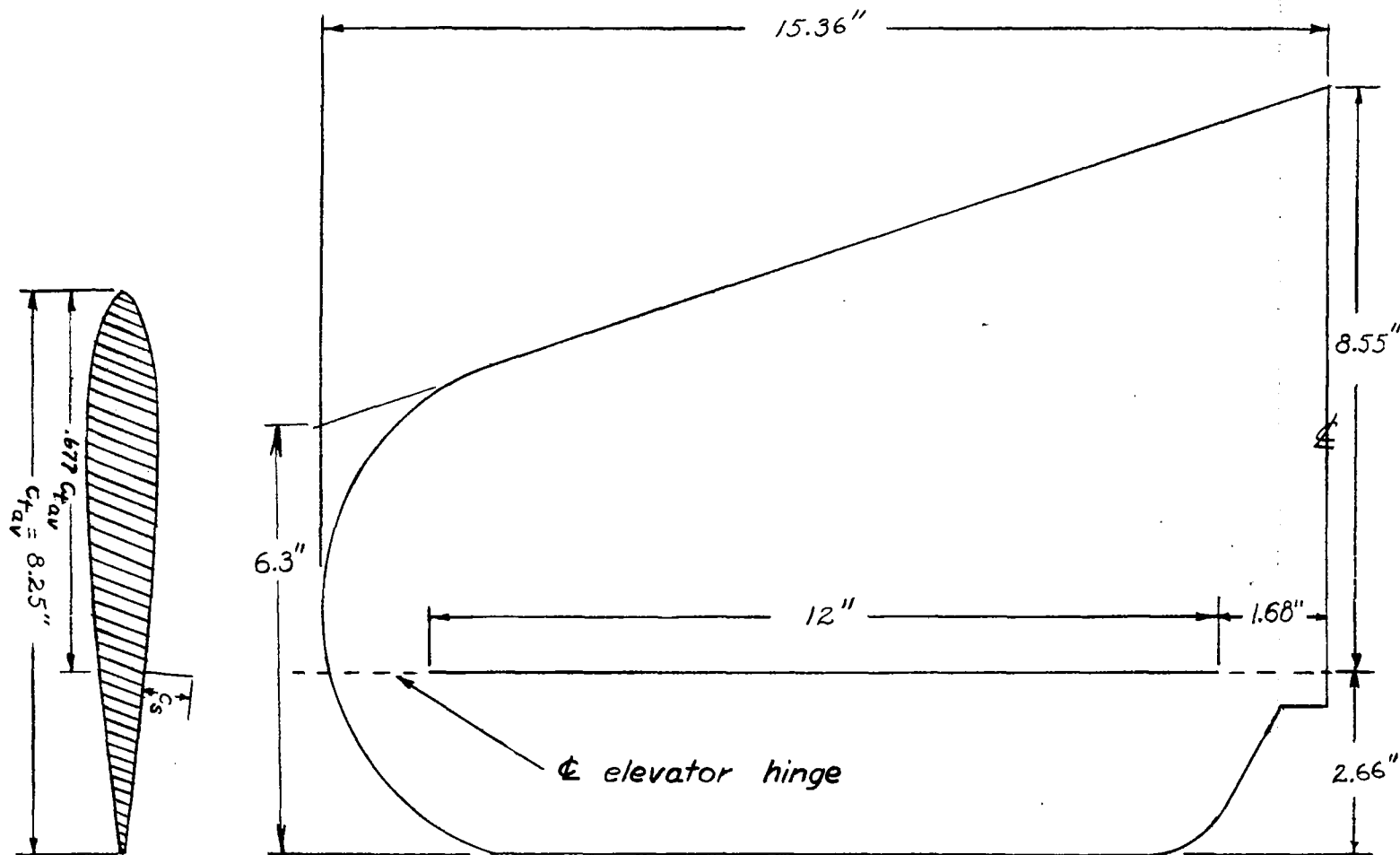


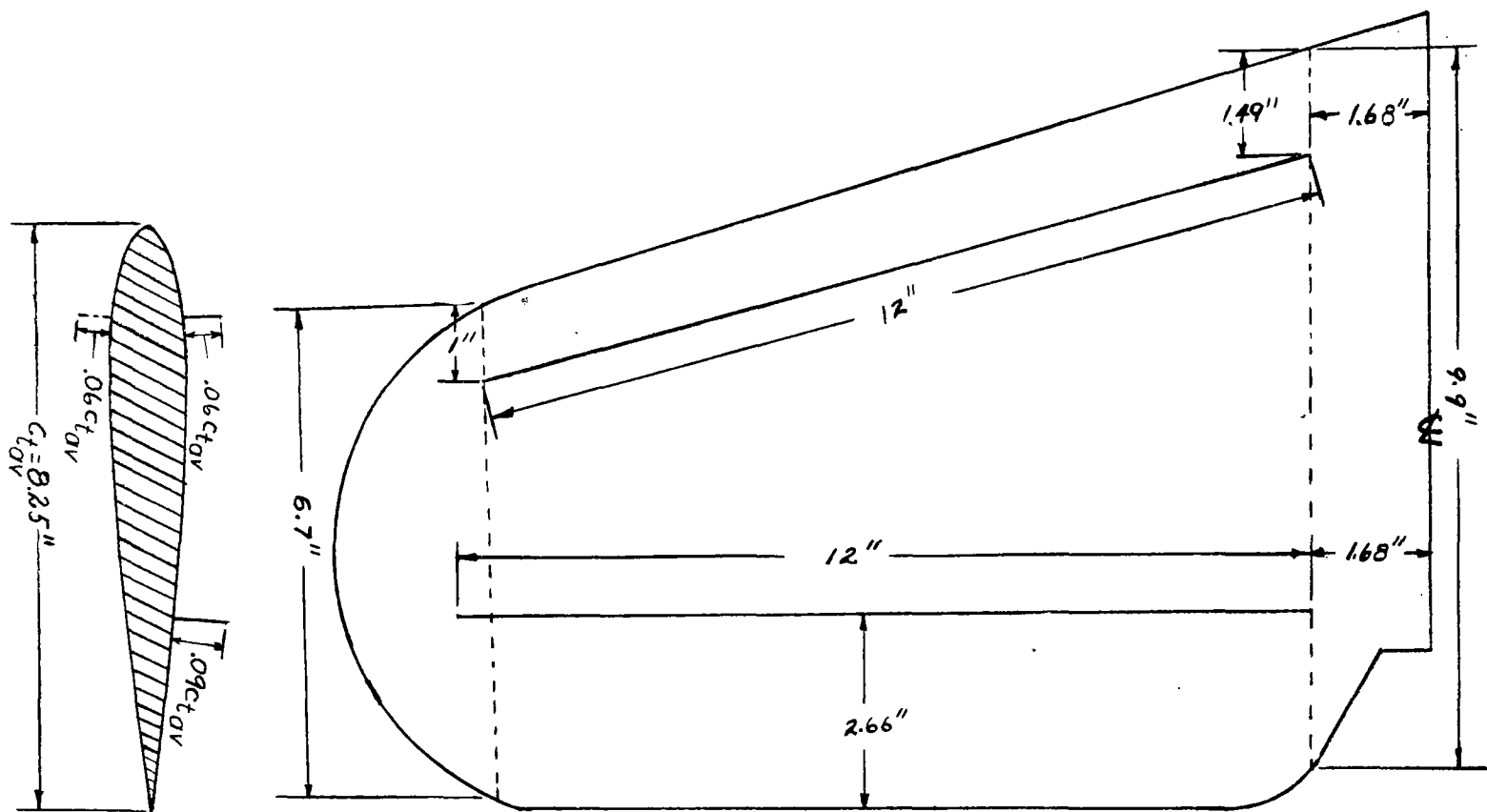
Figure 2.- Three-view drawing of model A.



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(a) Single spoiler.

Figure 3.- Location of spoilers on horizontal tail of model A.



(b) Combination spoilers.
Figure 3.- Concluded.

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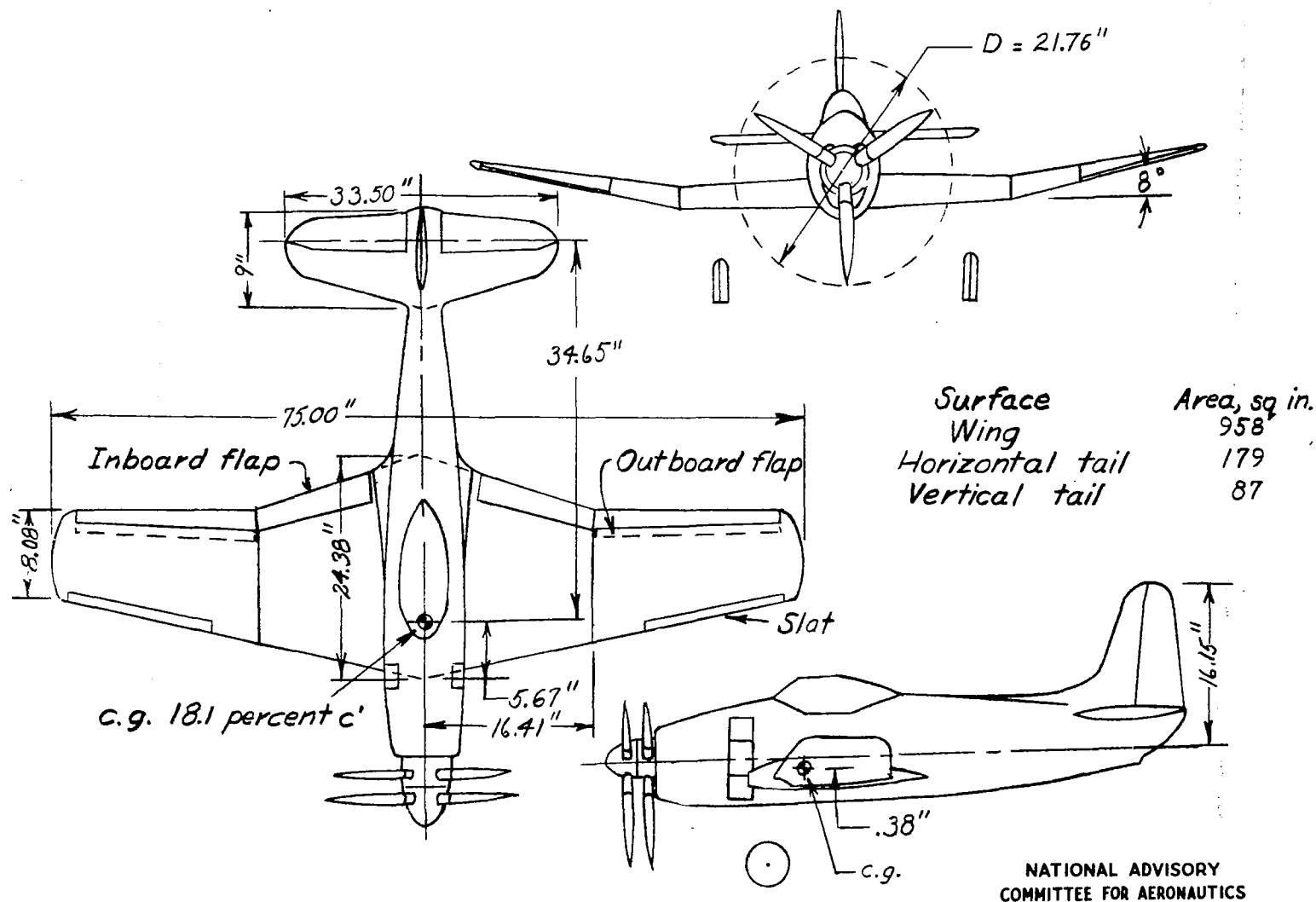
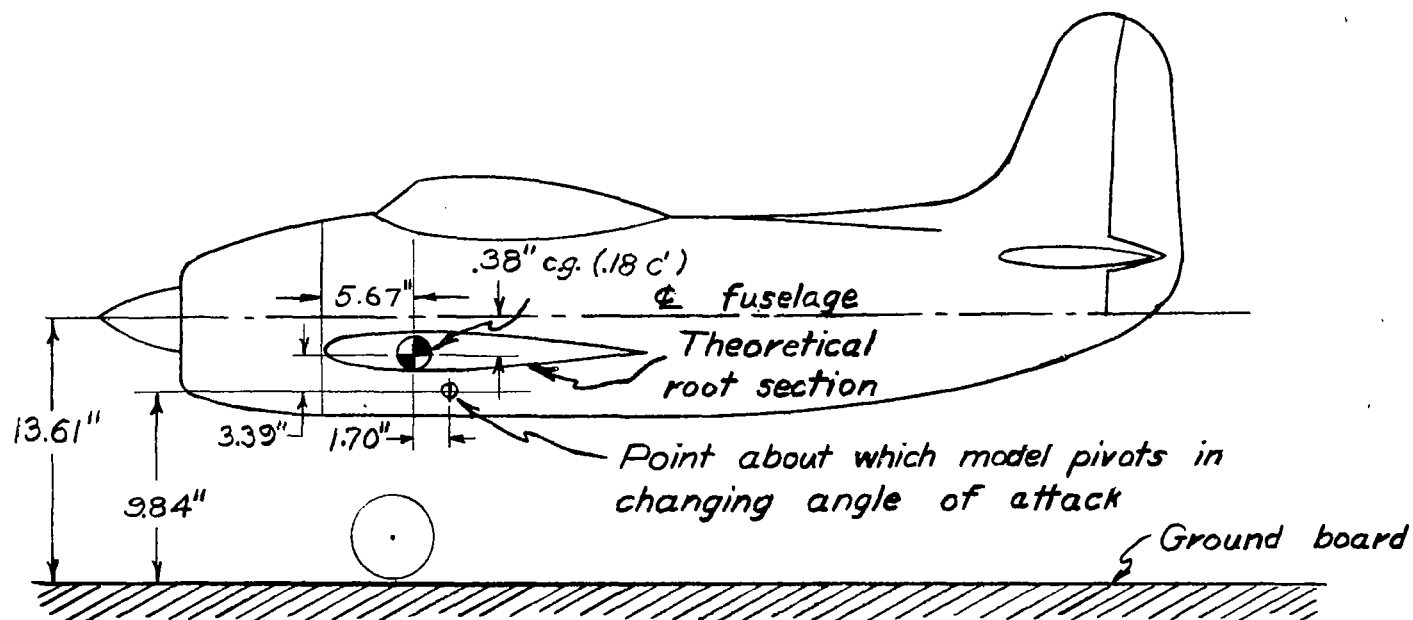
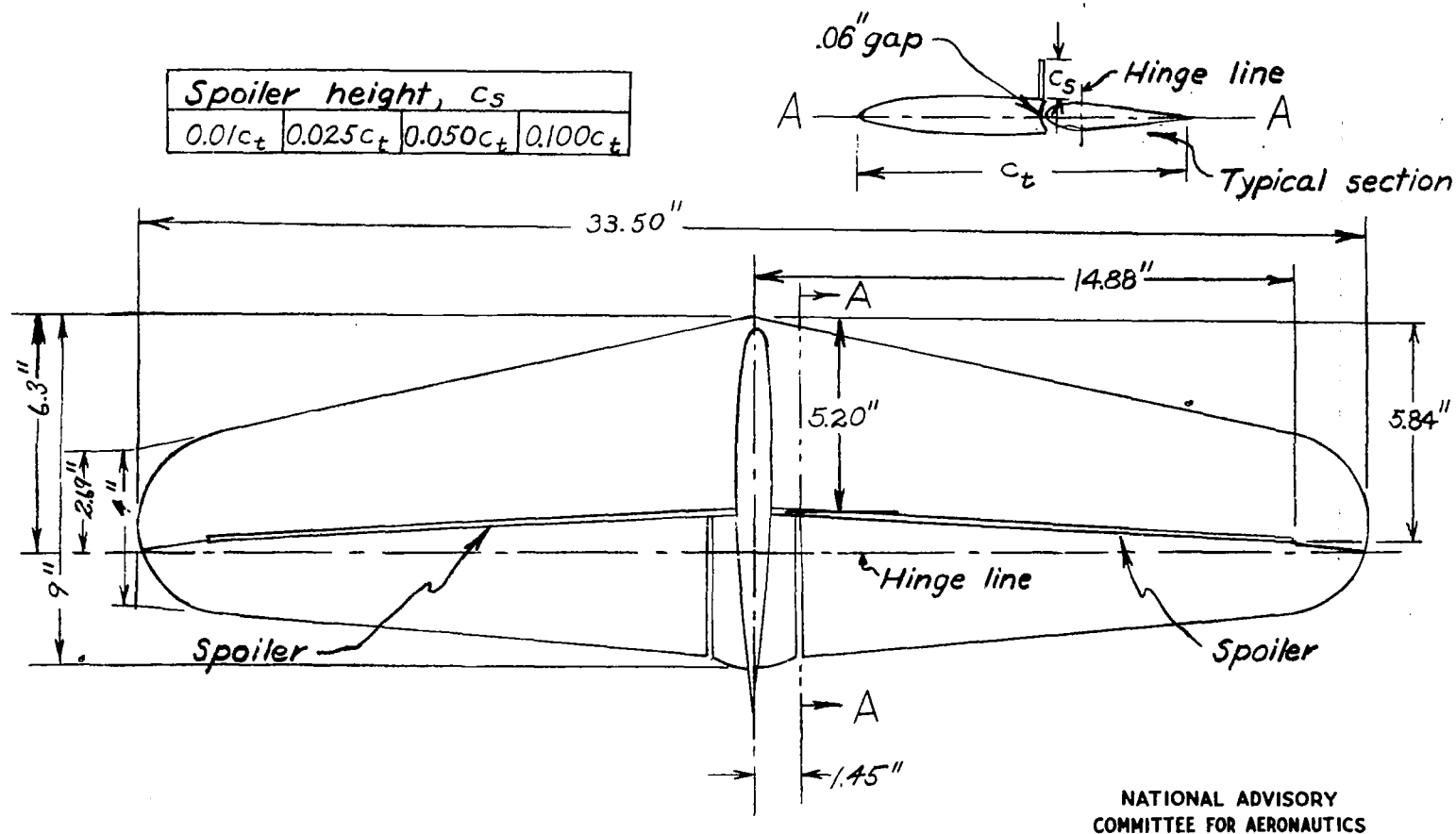


Figure 4.- Three-view drawing of model B.



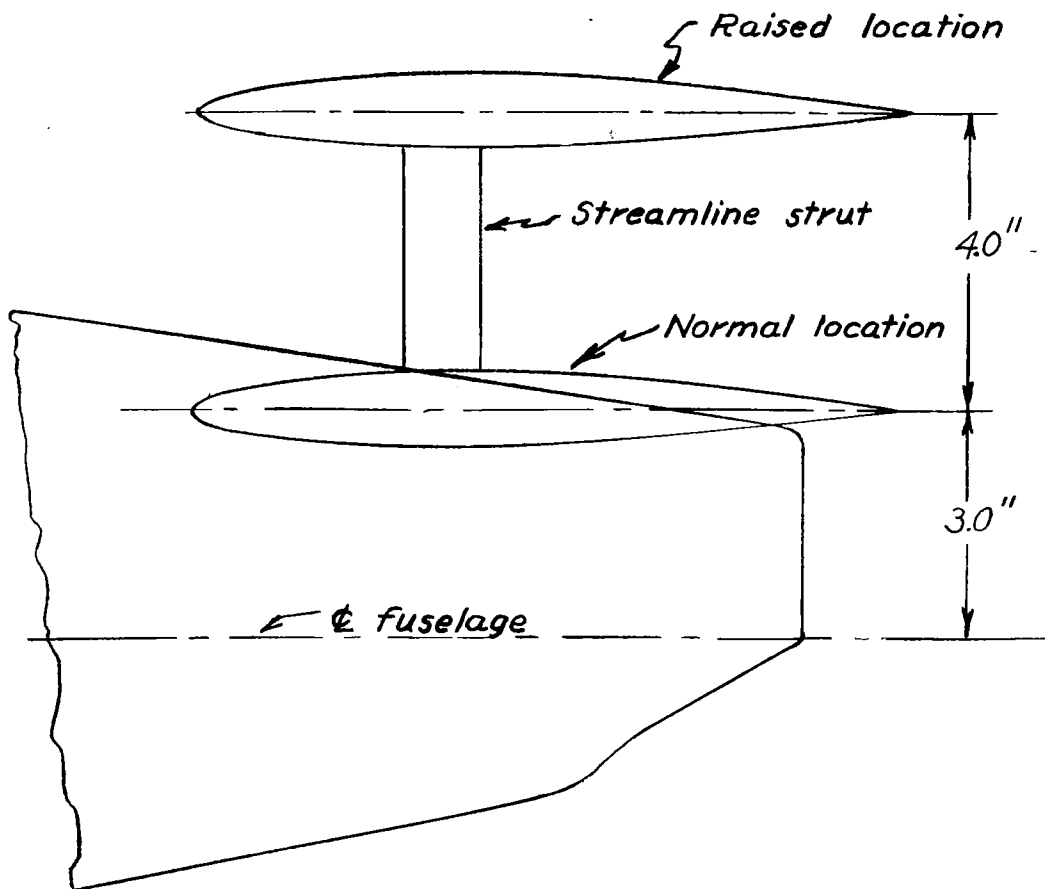
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Figure 5.- Location of model B near ground board.



(a) Dimensions of spoiler and model.

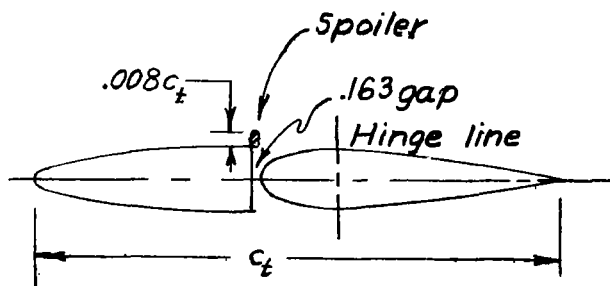
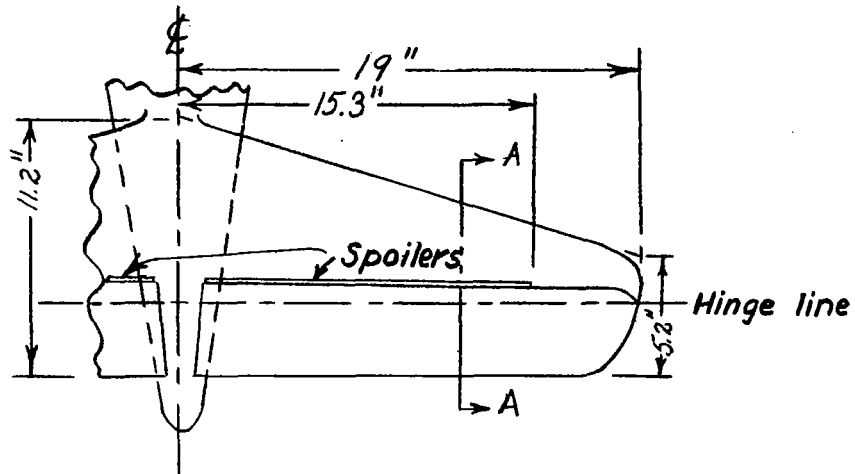
Figure 6.- Horizontal tail of model B.



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(b) Location of normal and raised
tail.

Figure 6.- Concluded.



Section A-A

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Figure 7.- Location of spoilers on horizontal tail of a typical fighter-airplane model.

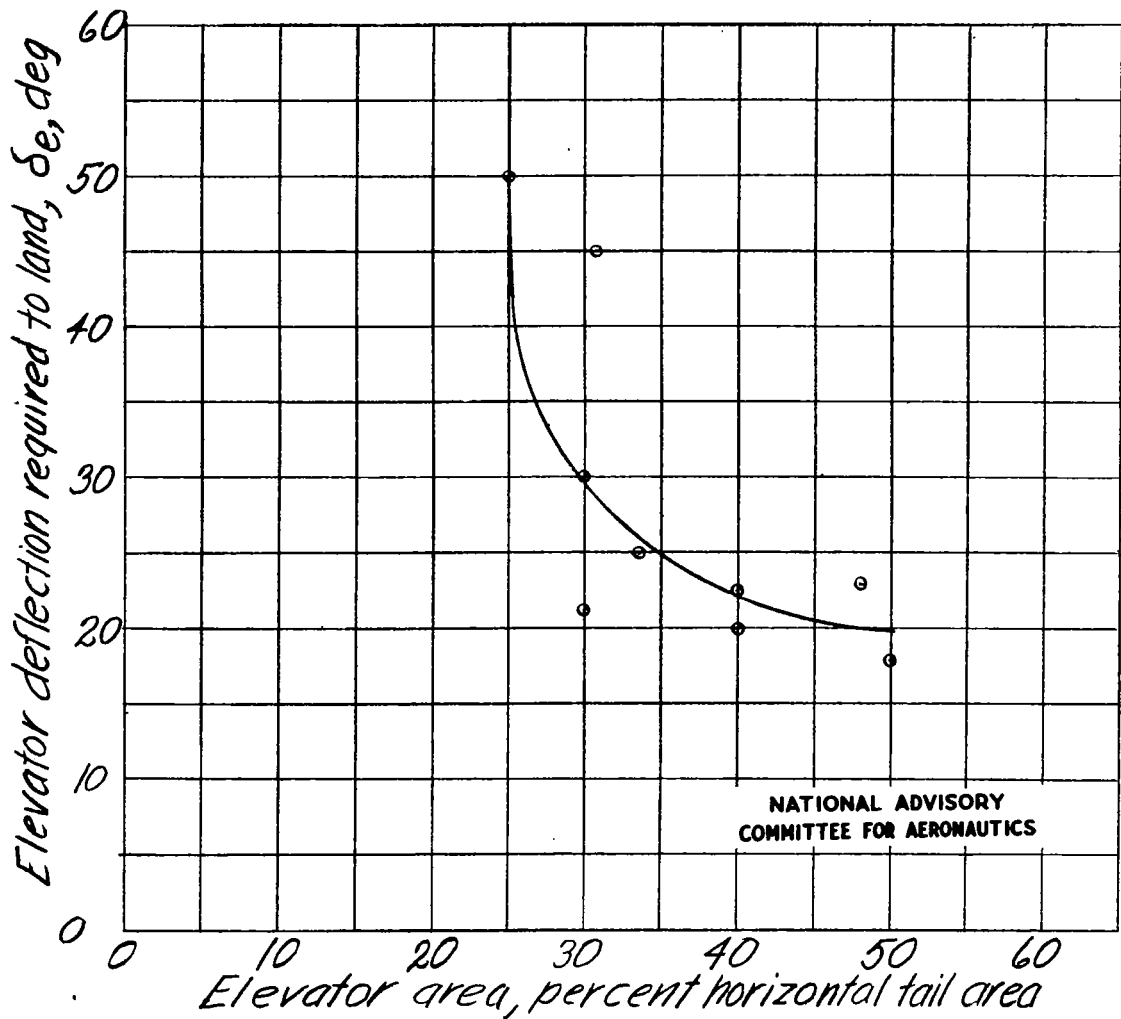


Figure 8.-Elevator deflection required to land as a function of elevator area for various fighter-airplane models. Models tested near ground board in Langley 7- by 10-foot tunnel.

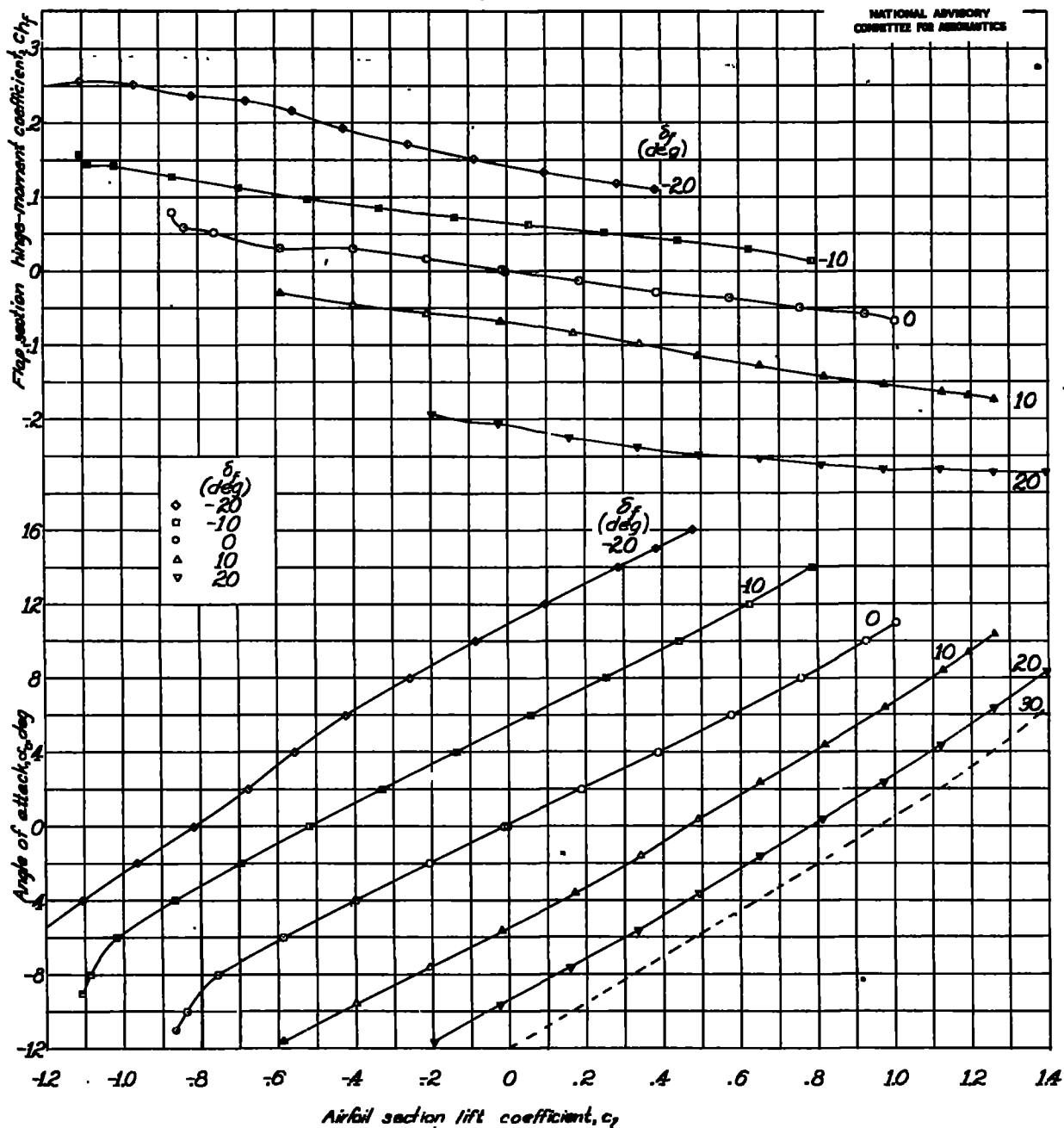


Figure 9.- Effect of flap deflection on the aerodynamic section characteristics of the plain airfoil. $\delta_c = 0^\circ$. (The curve for the flap deflection of 30° was obtained from reference 5.)

Fig. 9 Conc.

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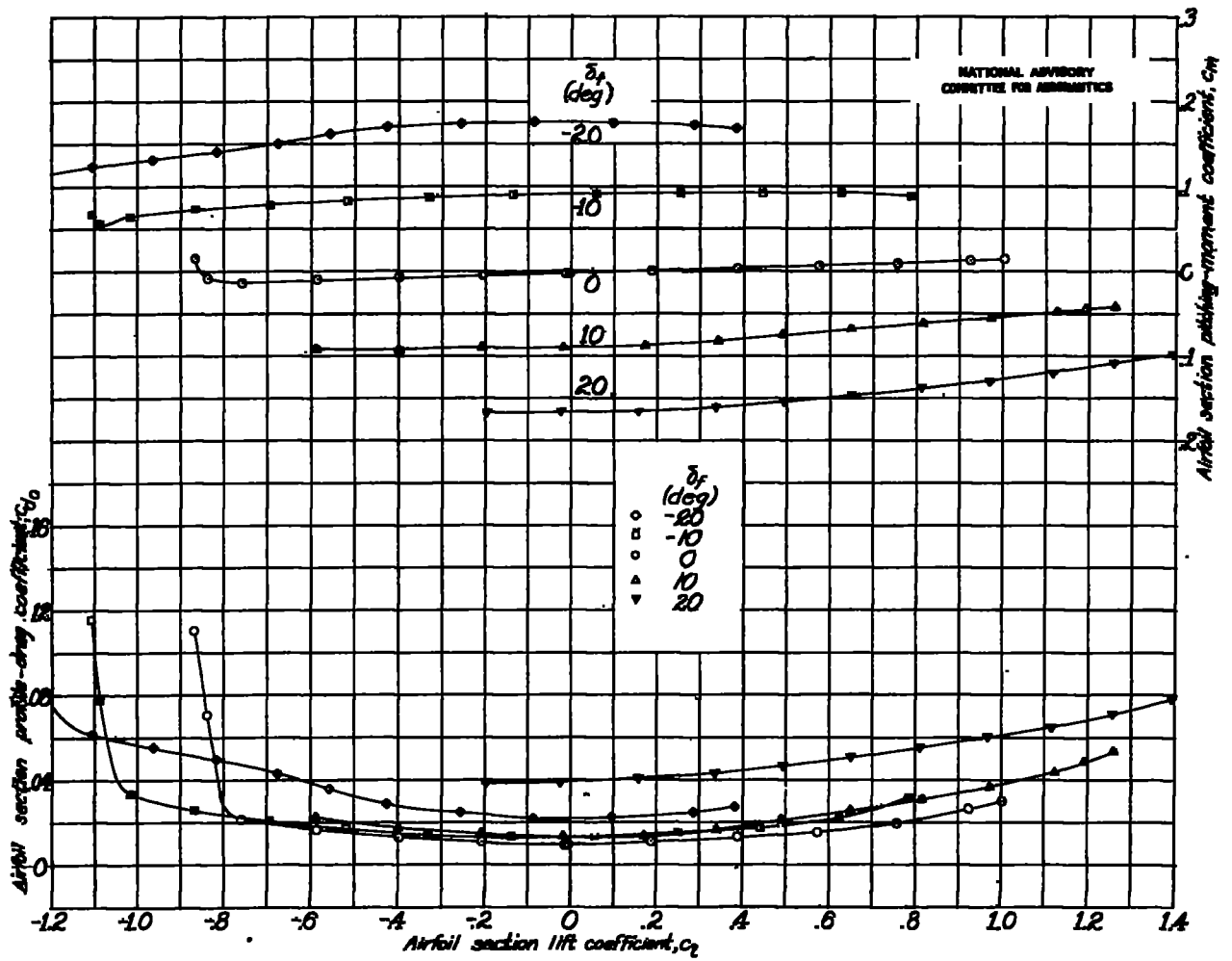


Figure 9.-Concluded.

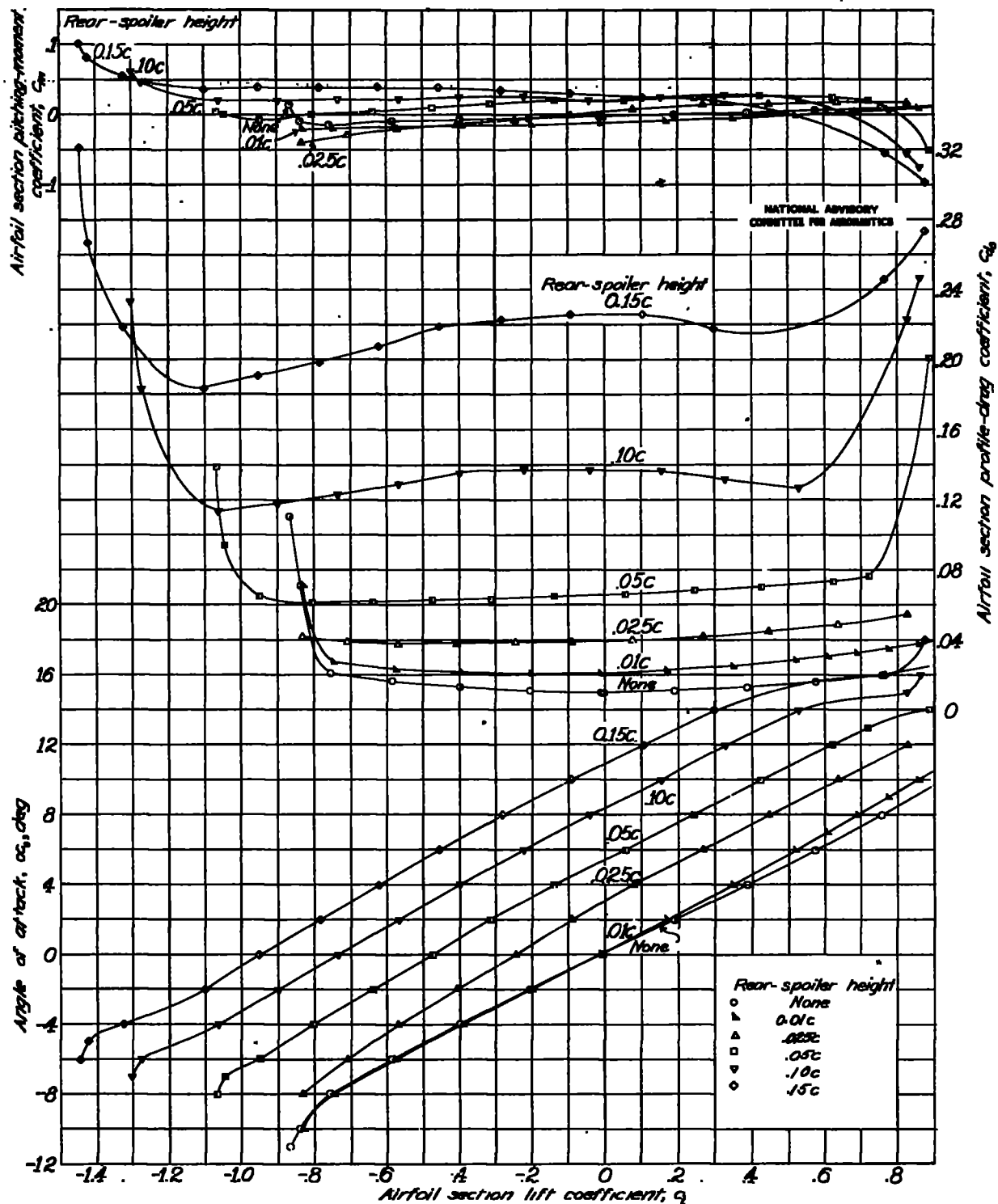


Figure 10.-Effect of rear-spoiler height on the aerodynamic section characteristics with spoiler at 0.65c on the upper surface of the airfoil $\delta_f = \delta_h = 0^\circ$.

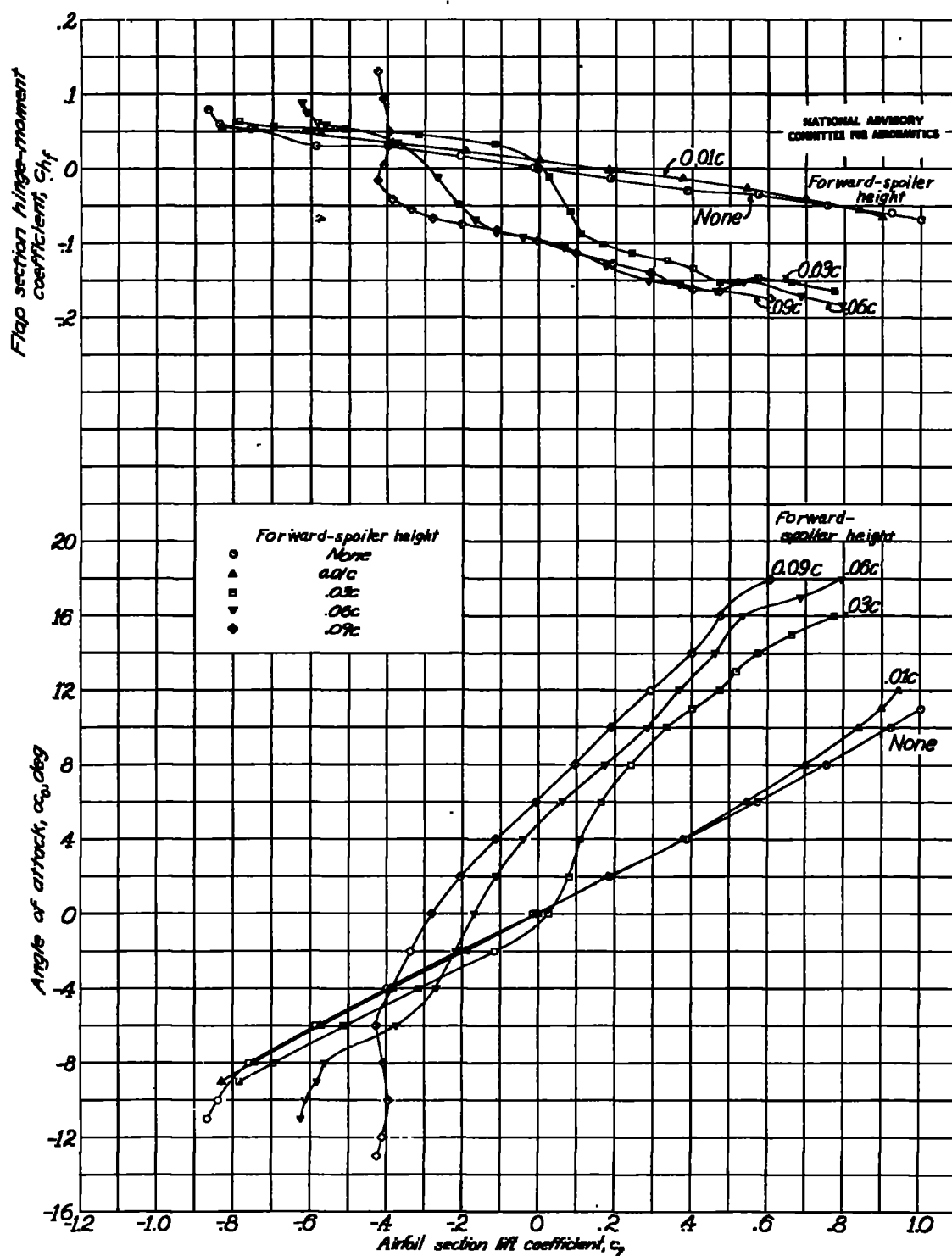


Figure 11.-Effect of forward-spoiler height, with constant flap deflection of 0° , on the aerodynamic section characteristics. Spoiler on upper surface at $0.15c$. $\delta_f = 0^\circ$.

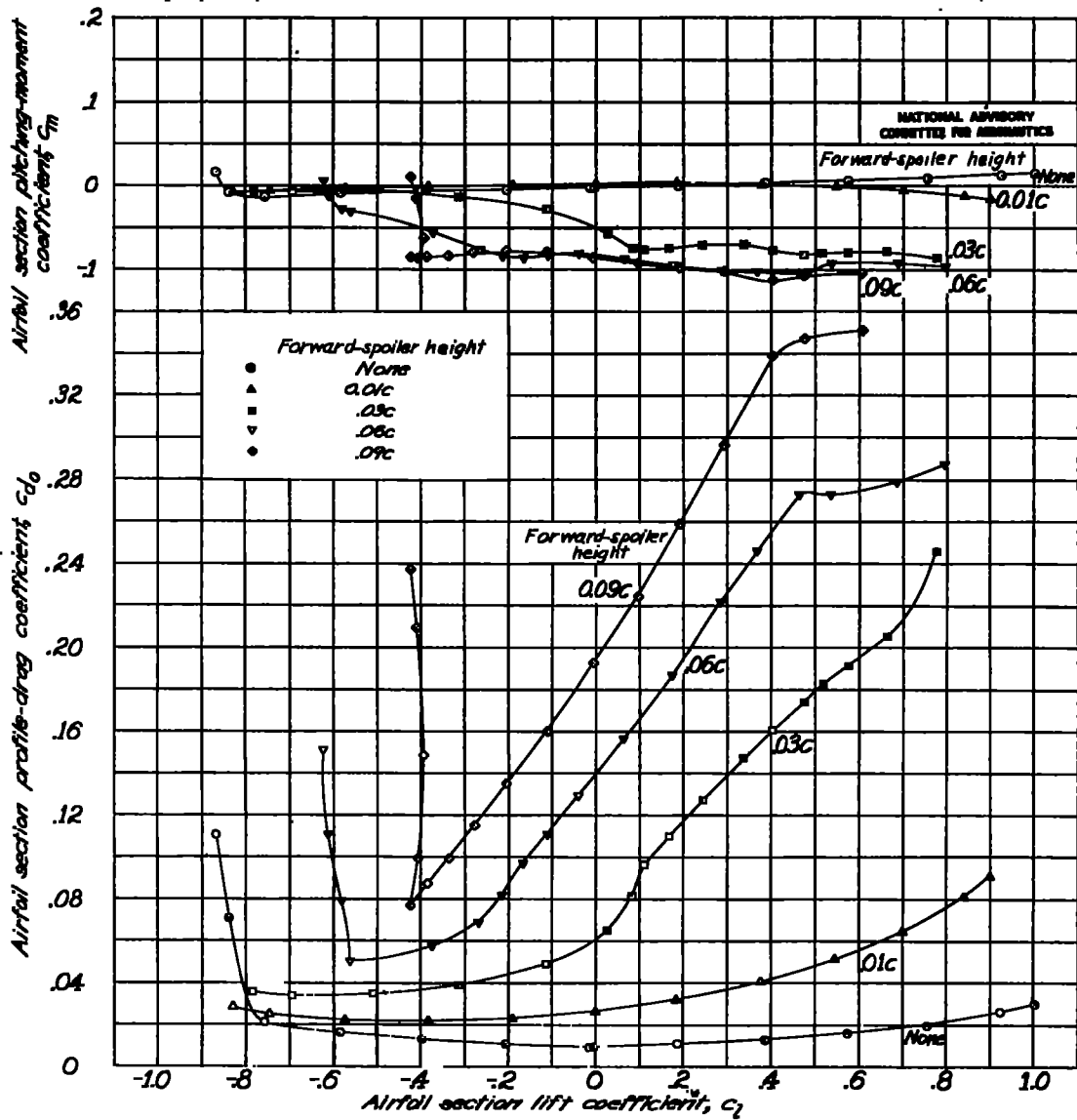
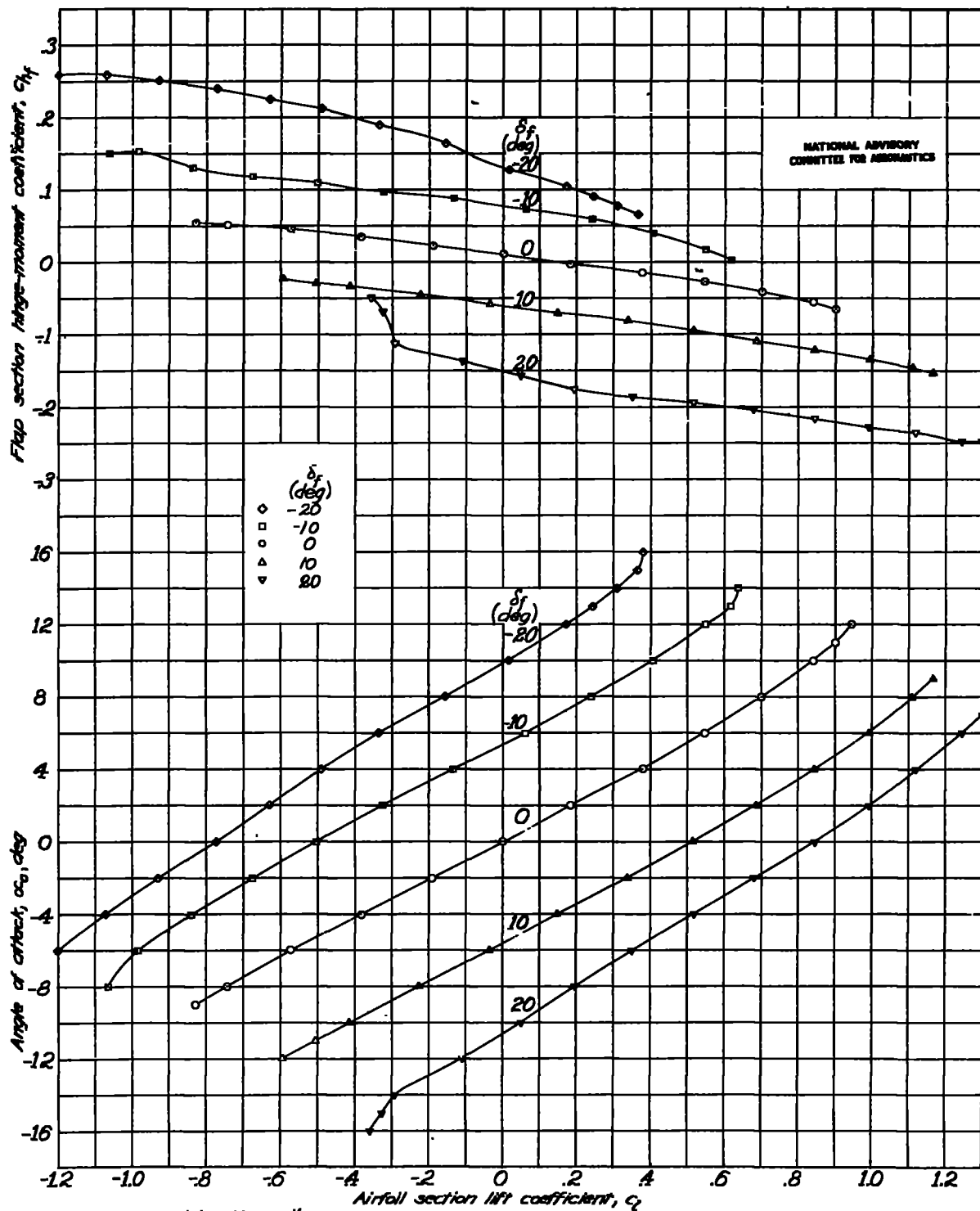


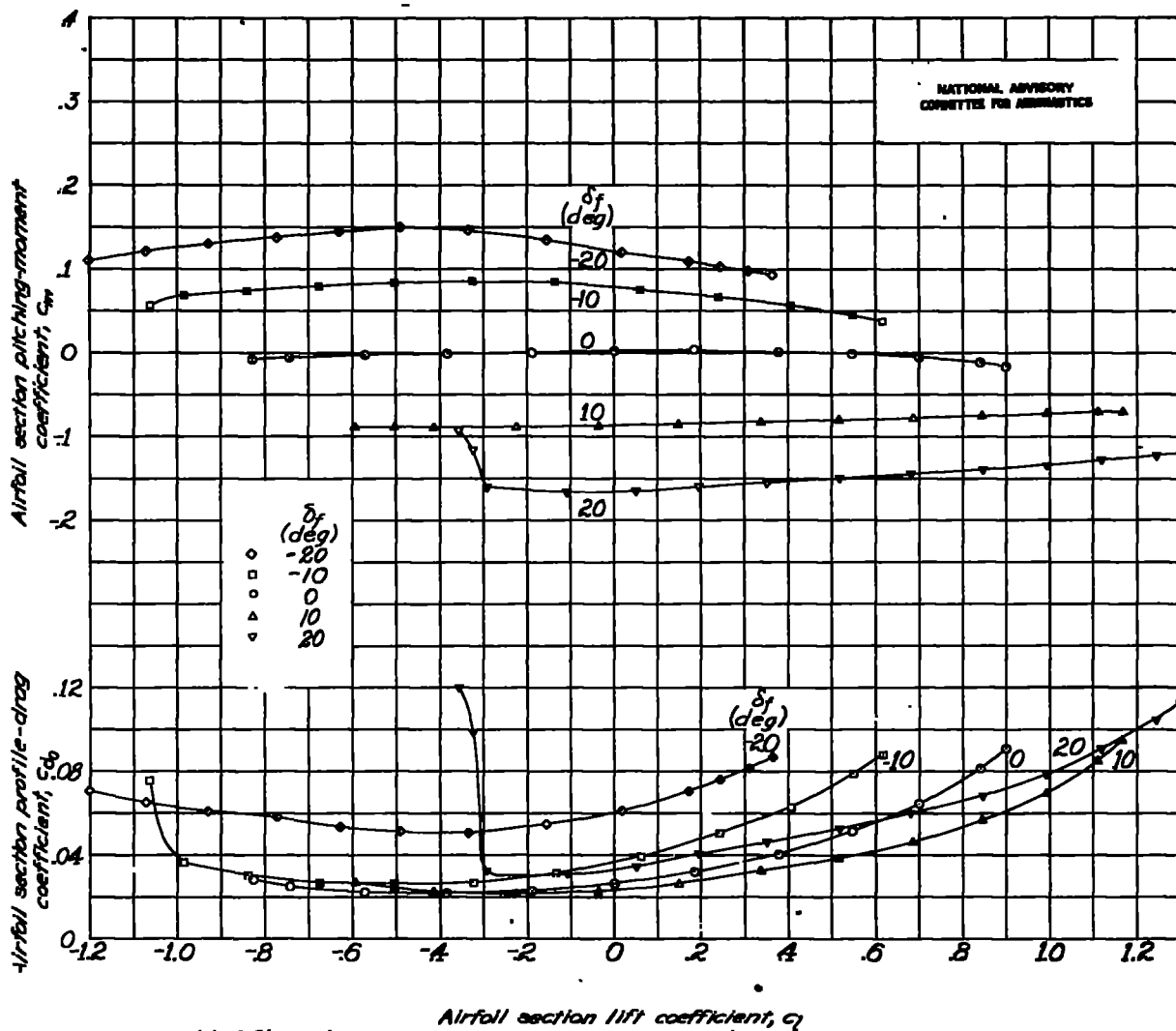
Figure 11.- Concluded.

Fig. 12a

NACA ARR No. L5F28



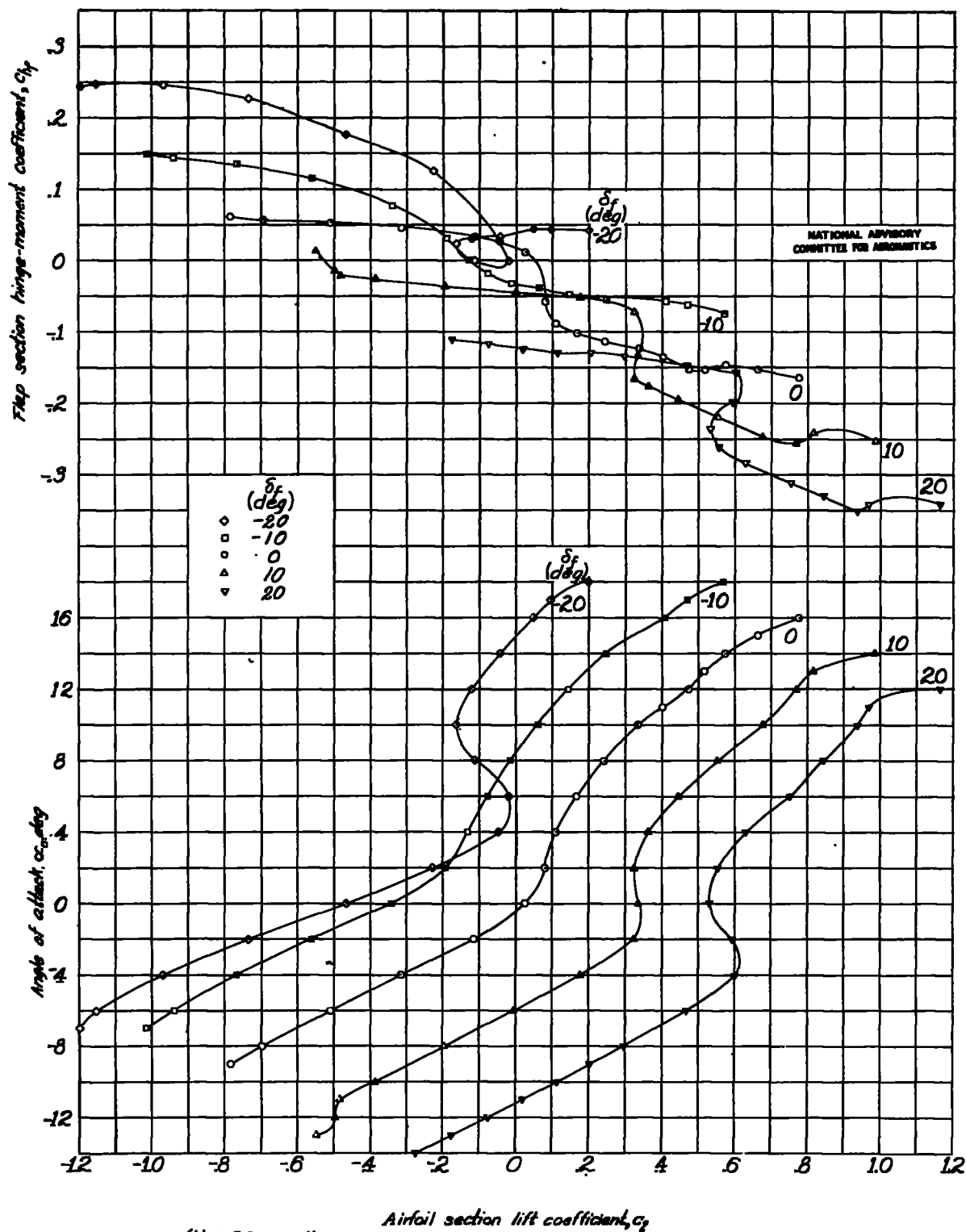
(a) 0010c spoiler.
 Figure 18.-Effect of flap deflection on the aerodynamic section characteristics with a spoiler at 0.15c on the upper surface of the airfoil. $\delta_s = 0^\circ$.



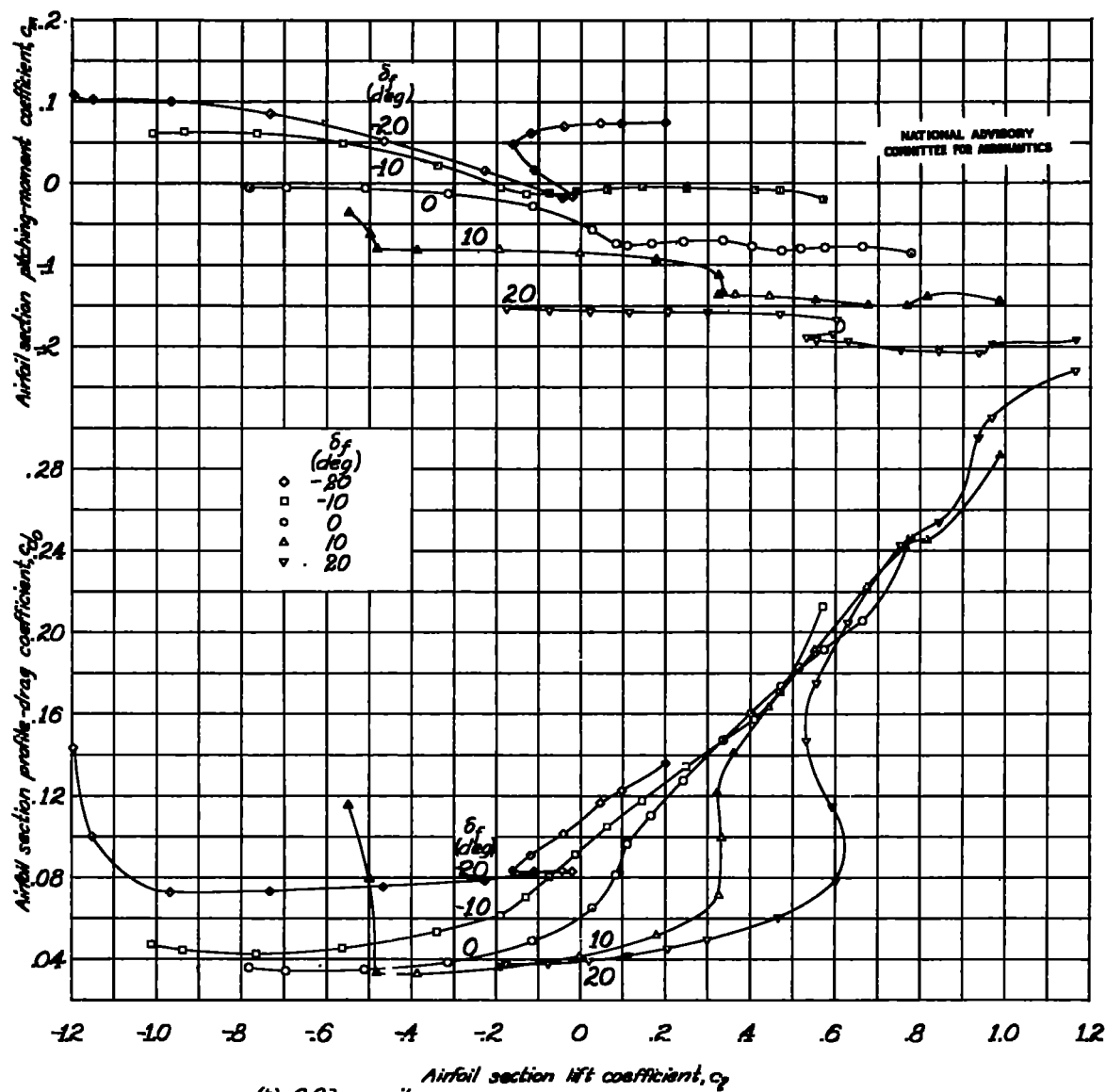
(a) 0.01c spoiler.
Figure 18.- Continued.

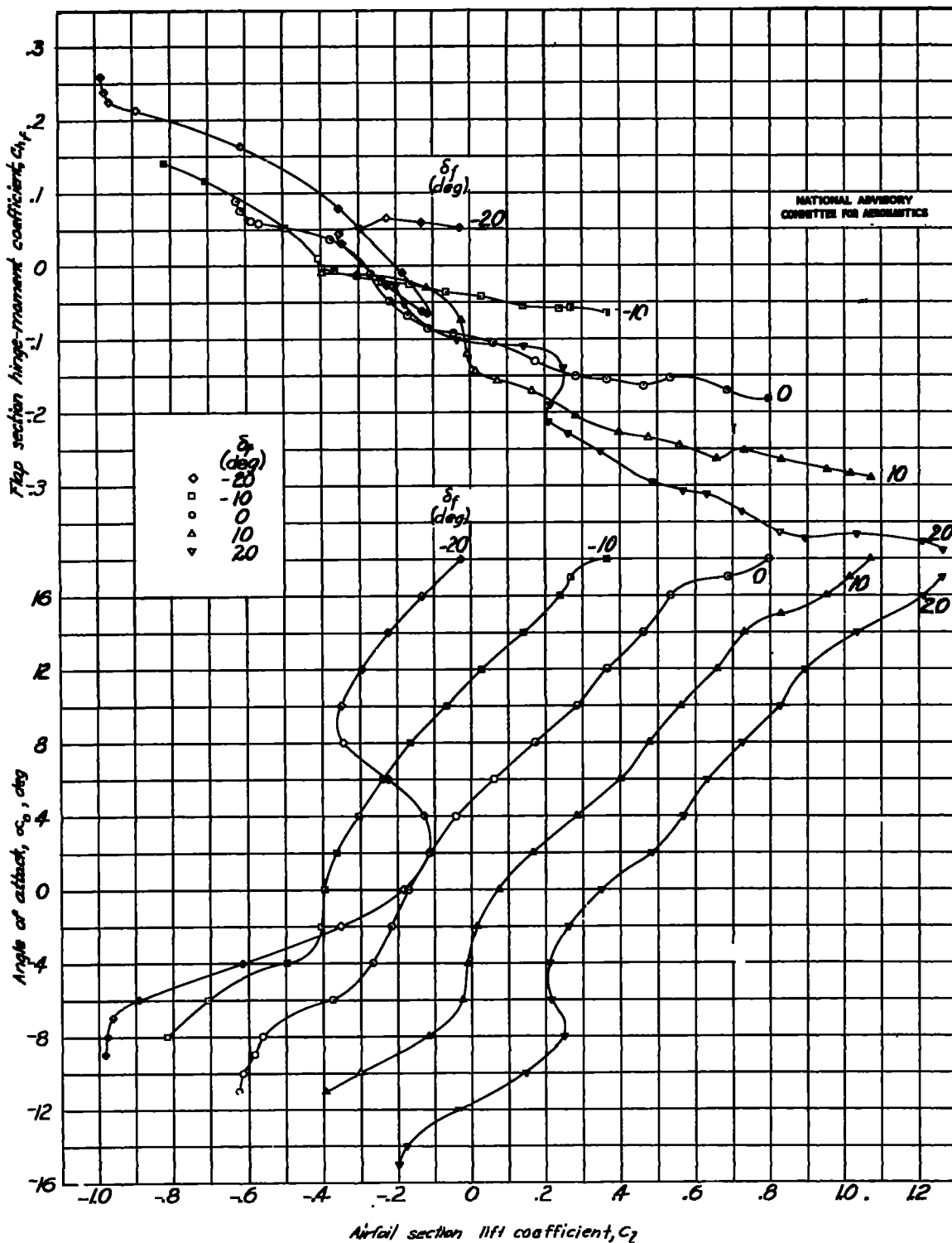
Fig. 12b

NACA ARR No. L5F28

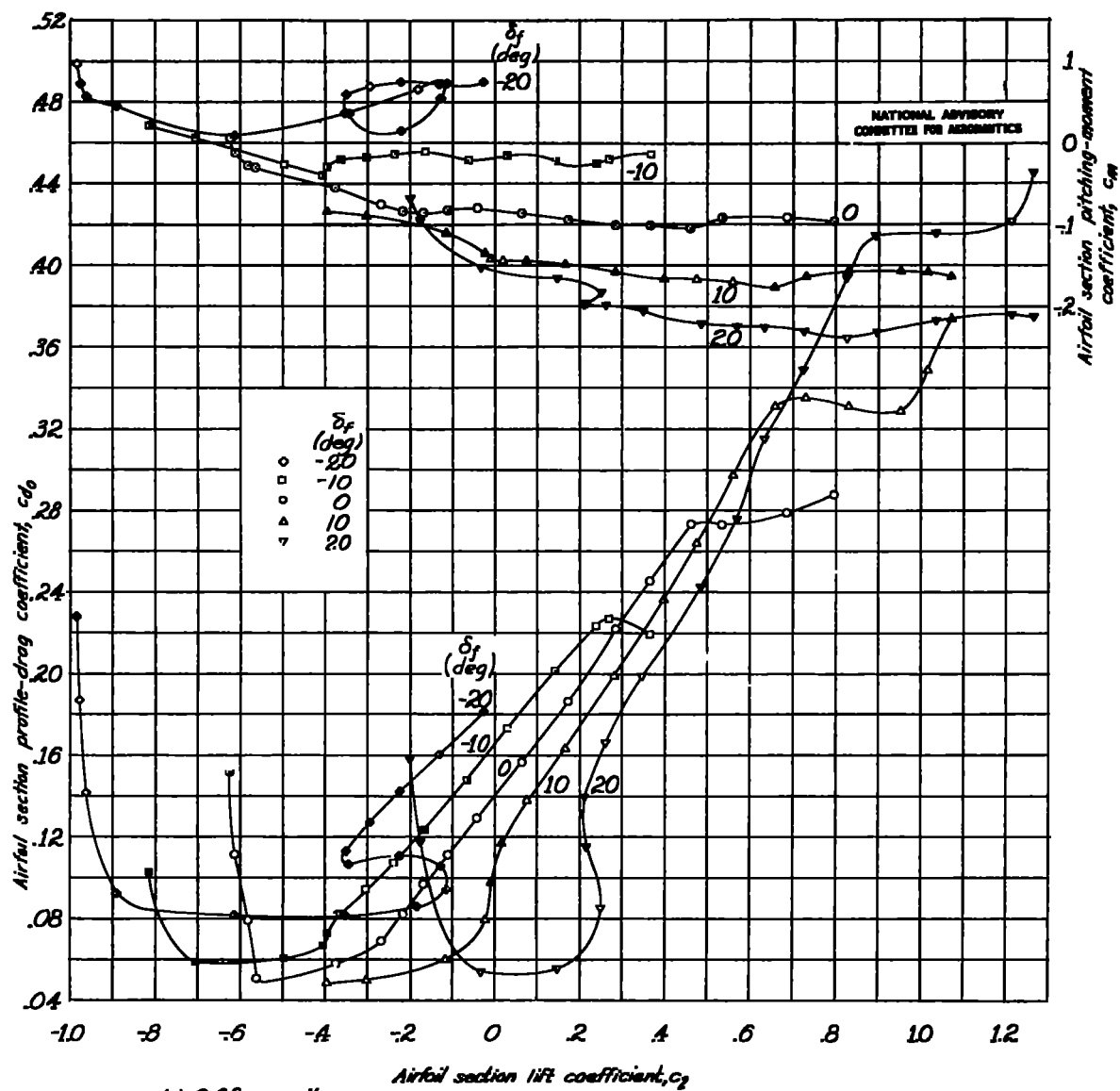


(b) 0.03c spoiler.
Figure 12.-Continued.





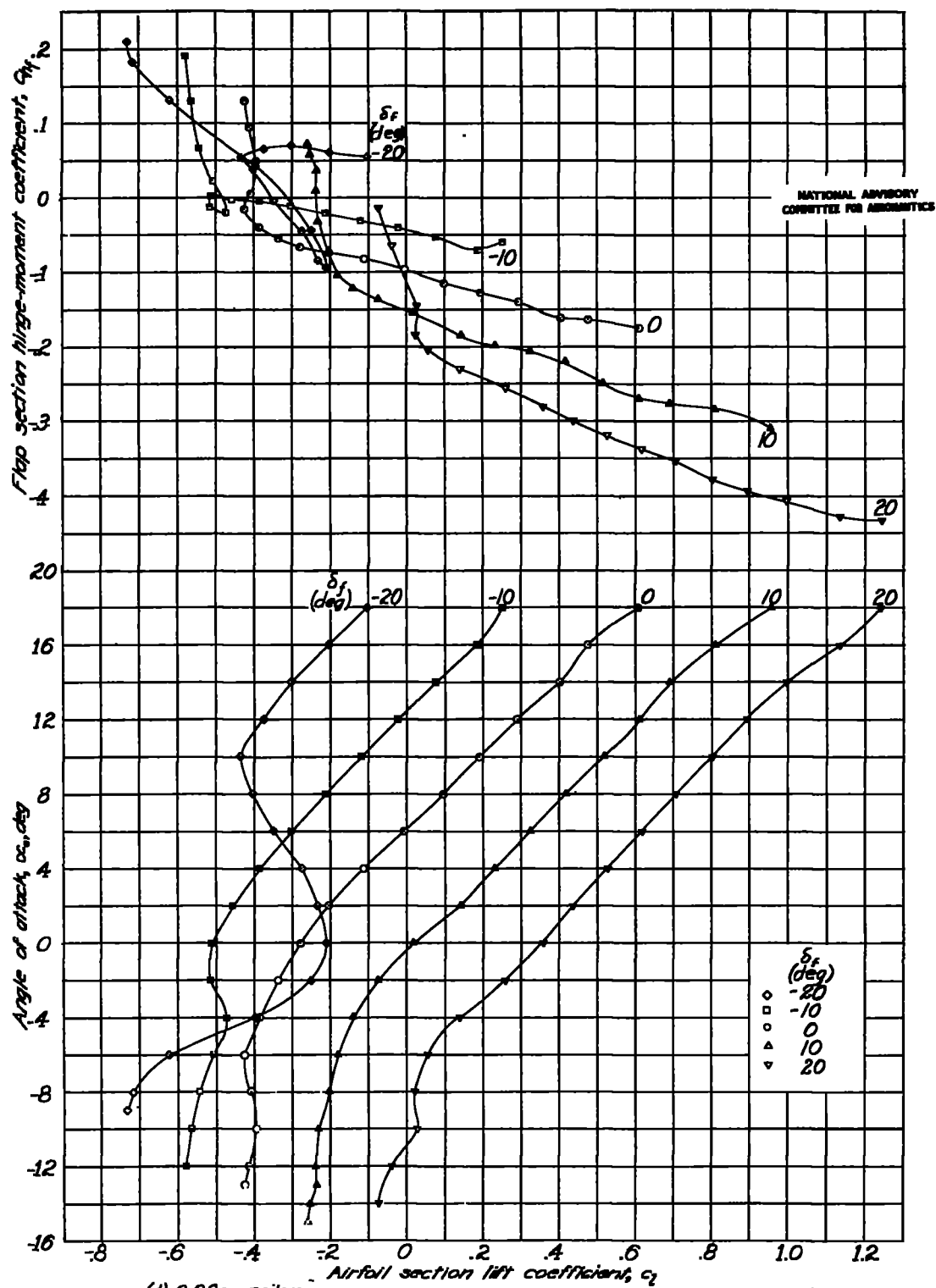
(c) 0.06c spoiler.
Figure 12.-Continued.

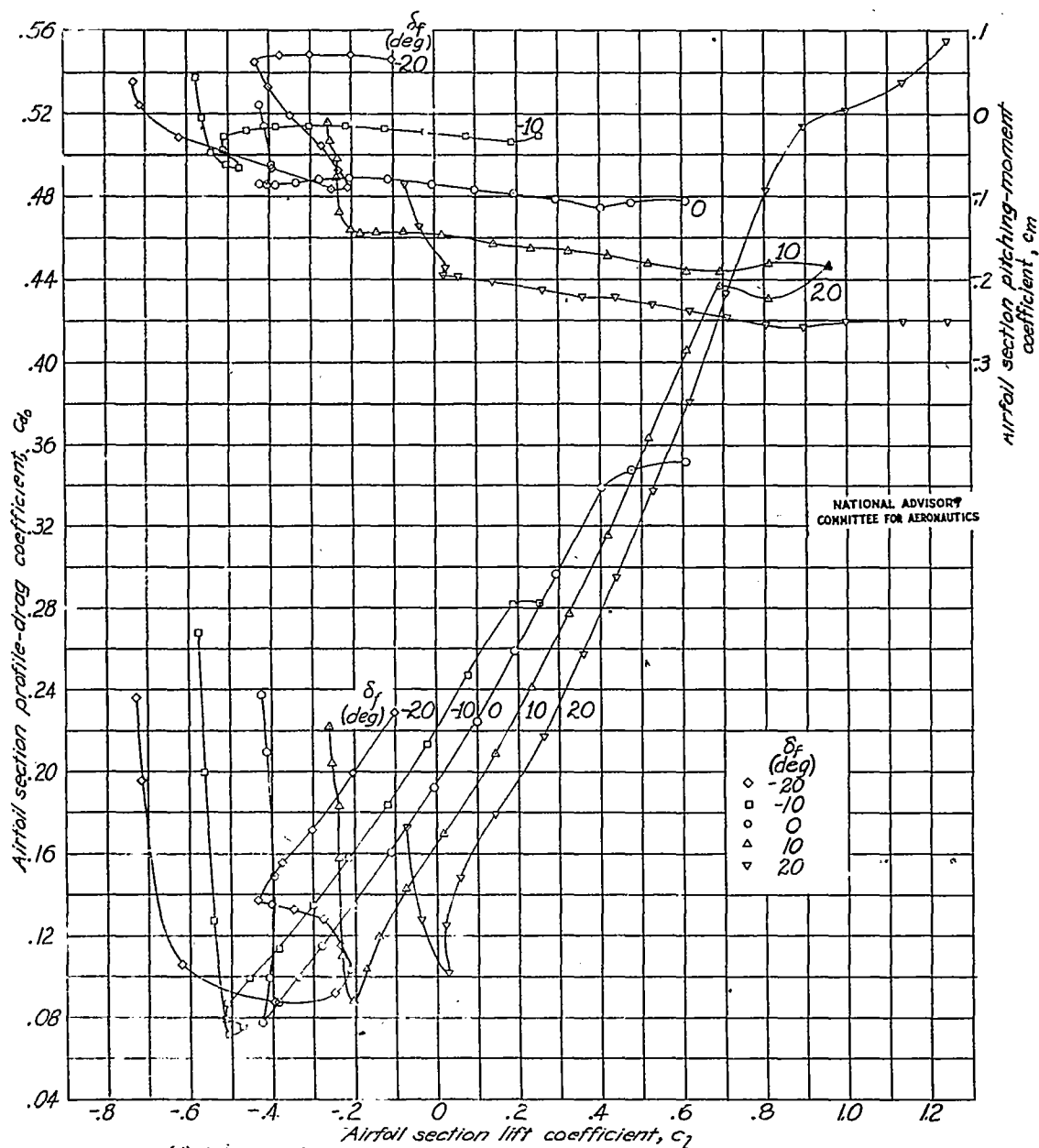


(c) 0.06c spoiler.
Figure 12.- Continued.

Fig. 12d

NACA ARR No. L5F28





(d) 0.89c spoiler.
Figure 12.- Concluded.

Fig. 13a

NACA ARR No. L5F28

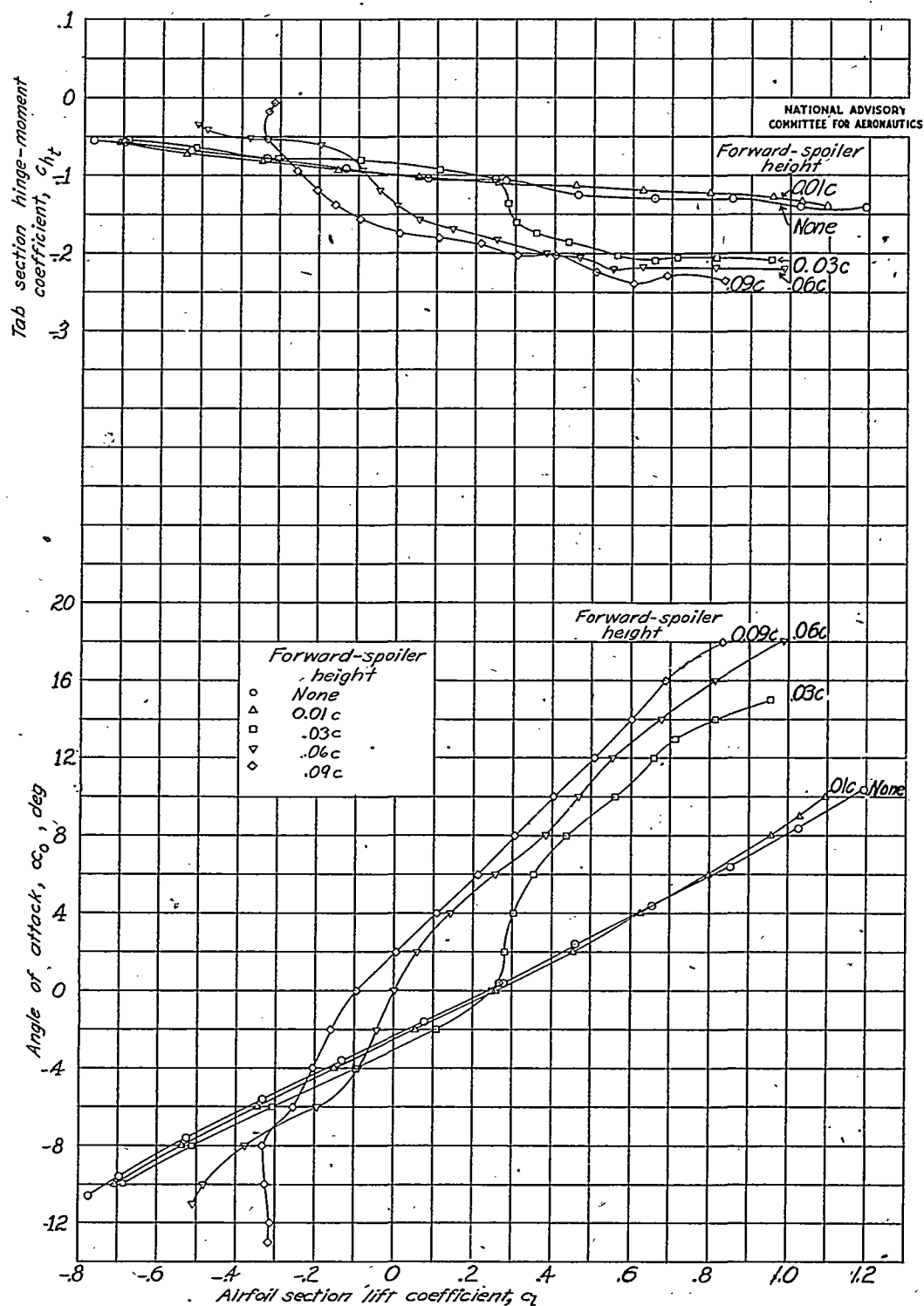


Figure 13.-Effect of forward-spoiler height, with constant tab deflection, on the aerodynamic section characteristics. Spoiler on upper surface at $0.15c$. $\delta_f = 0^\circ$.

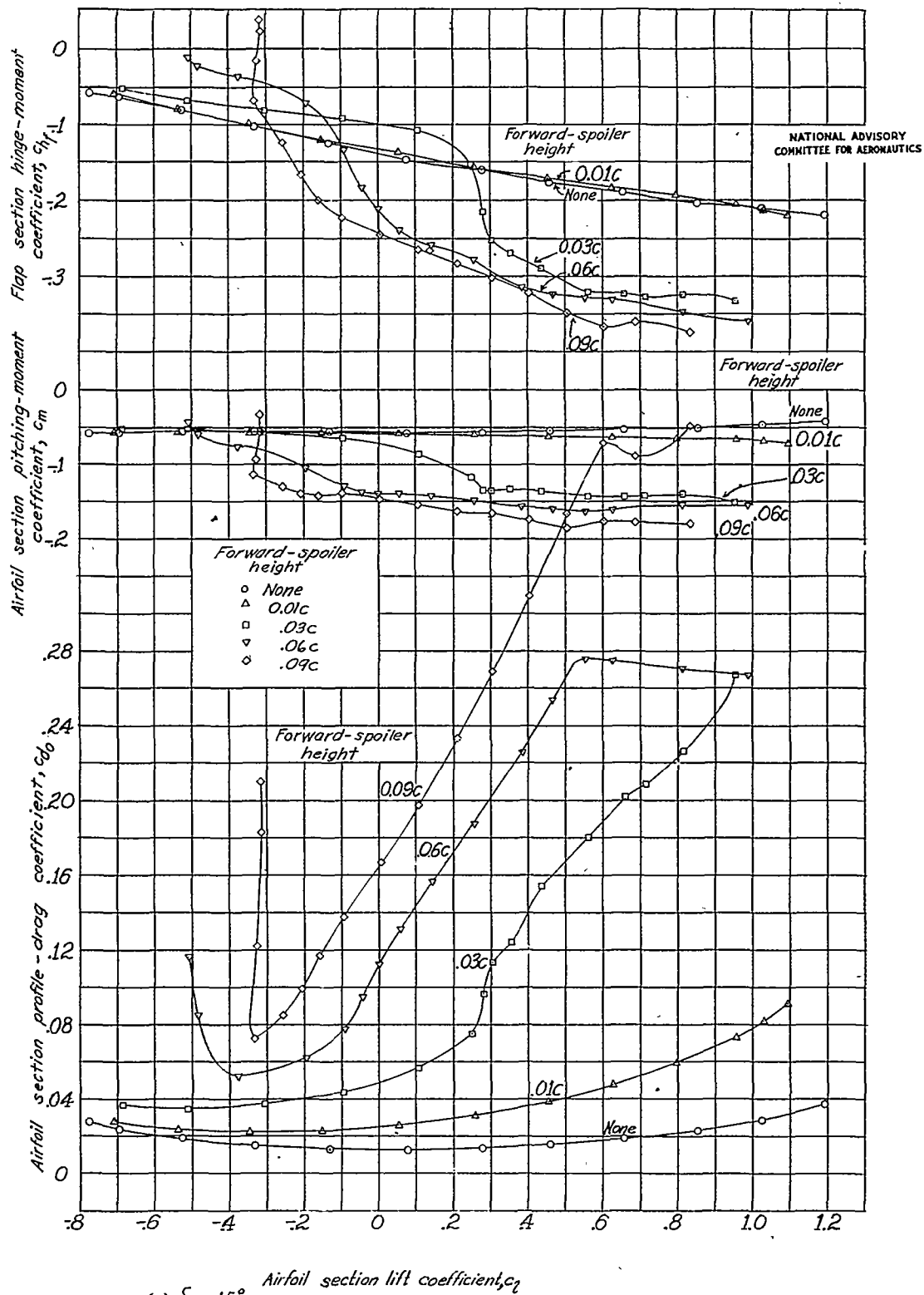
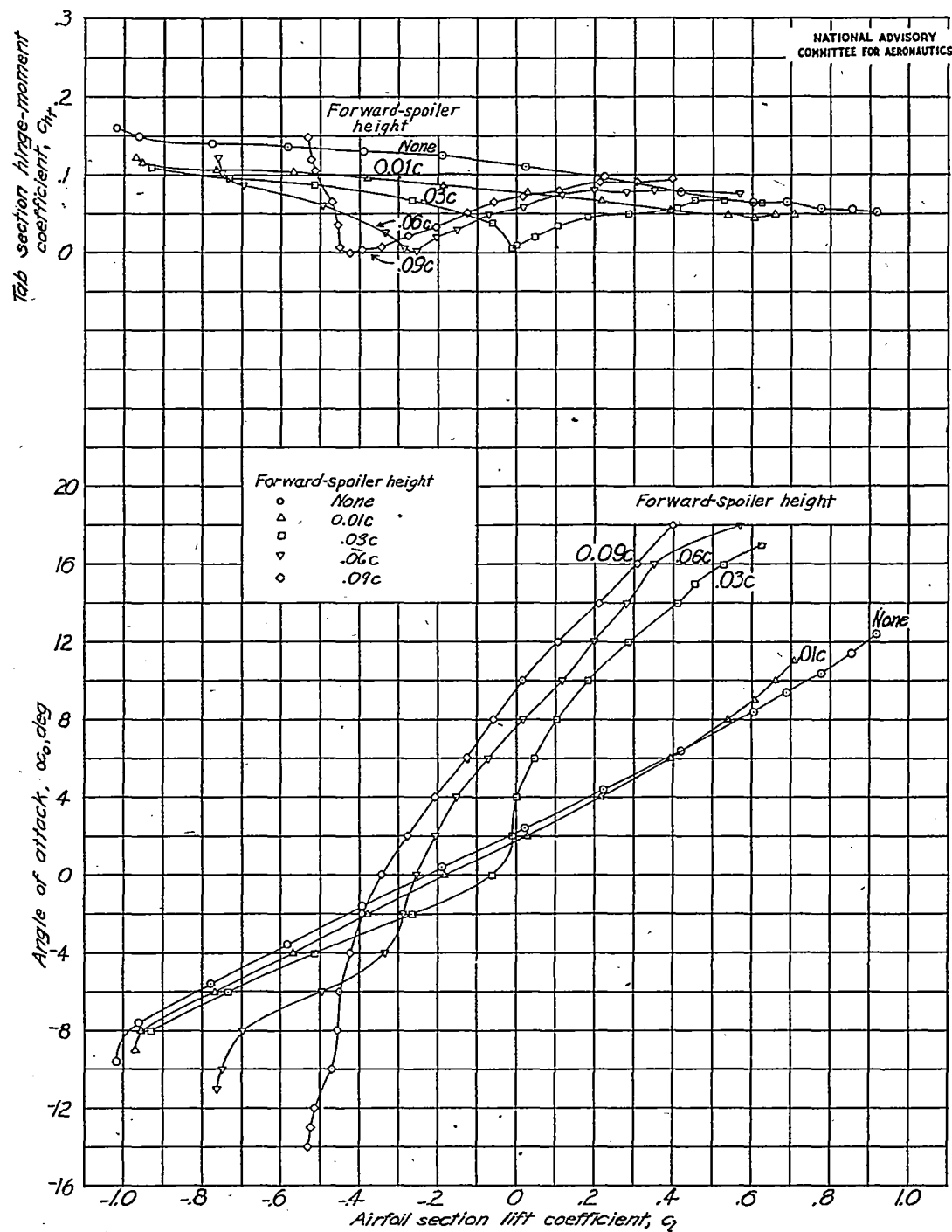
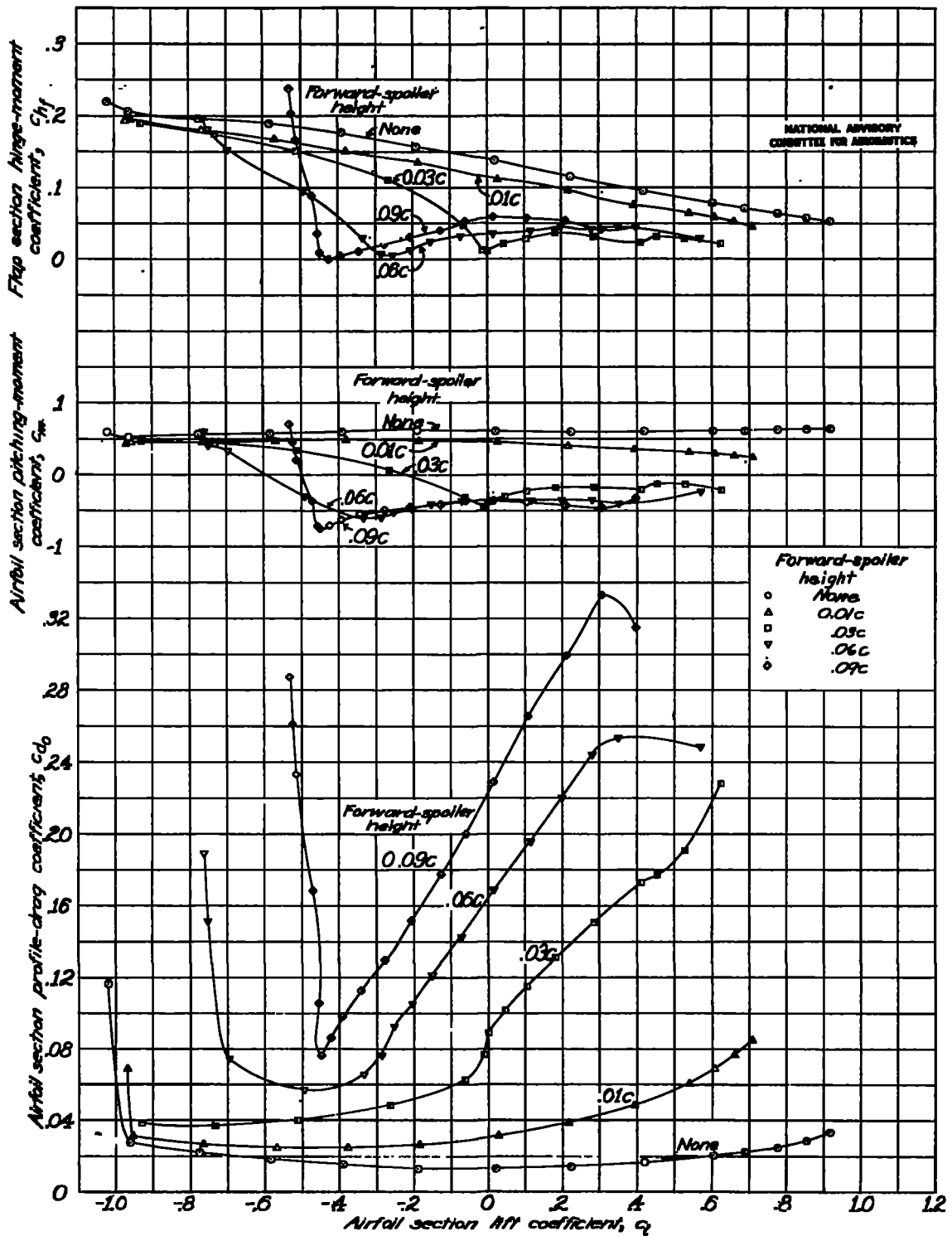


Fig. 13b

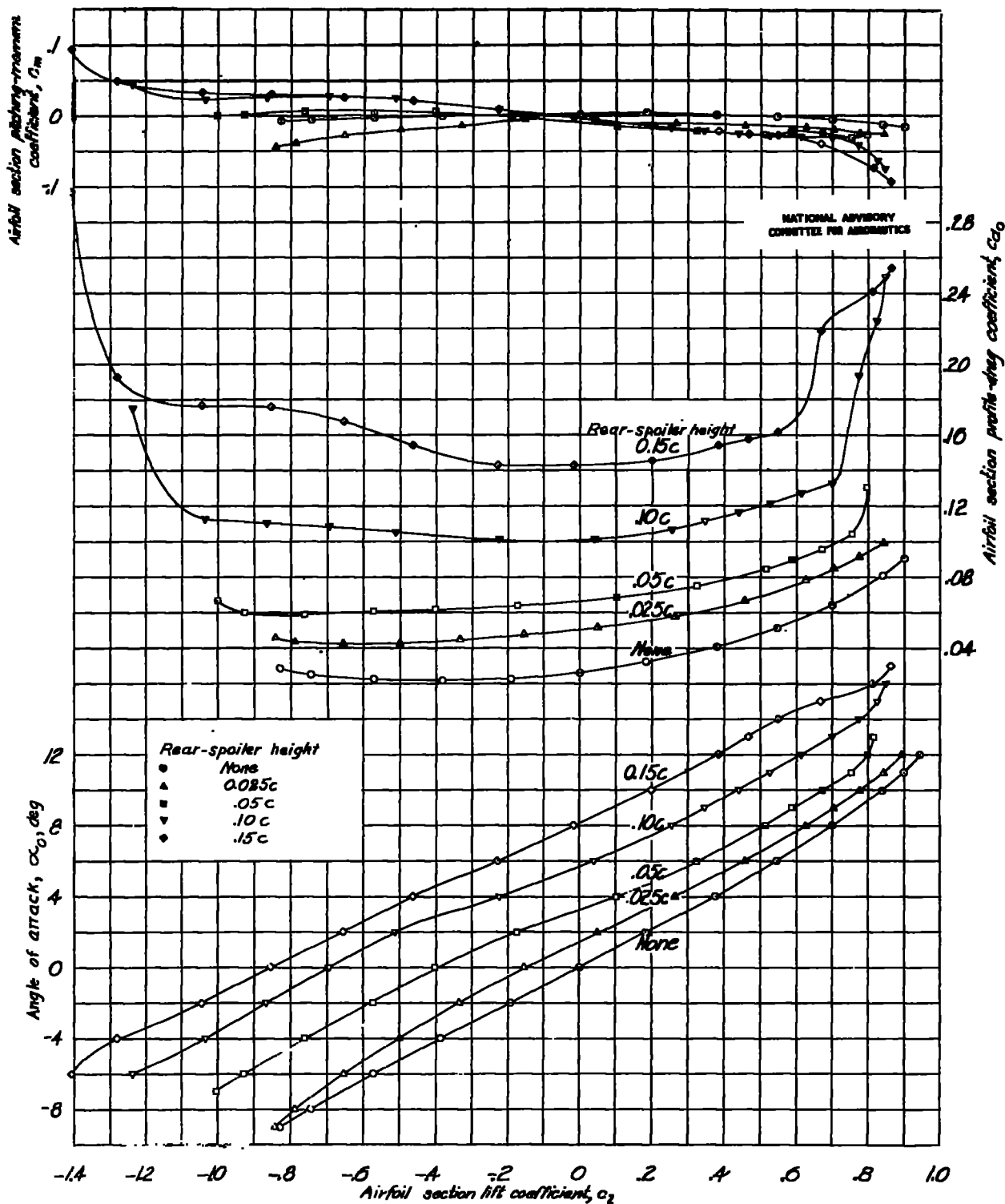
NACA ARR No. L5F28



(b) $\delta_t = -15^\circ$
Figure 13.- Continued.



(b) $\delta_1 = -15^\circ$.
Figure 13- Concluded.



(a) 0.01c forward spoiler.
 Fig. 14. Effect of rear spoiler height on the aerodynamic section characteristics with a rear spoiler at 0.65c and with a constant-height spoiler at 0.15c; both spoilers on the upper surface of the airfoil; $\delta_f = \delta_r = 0$.

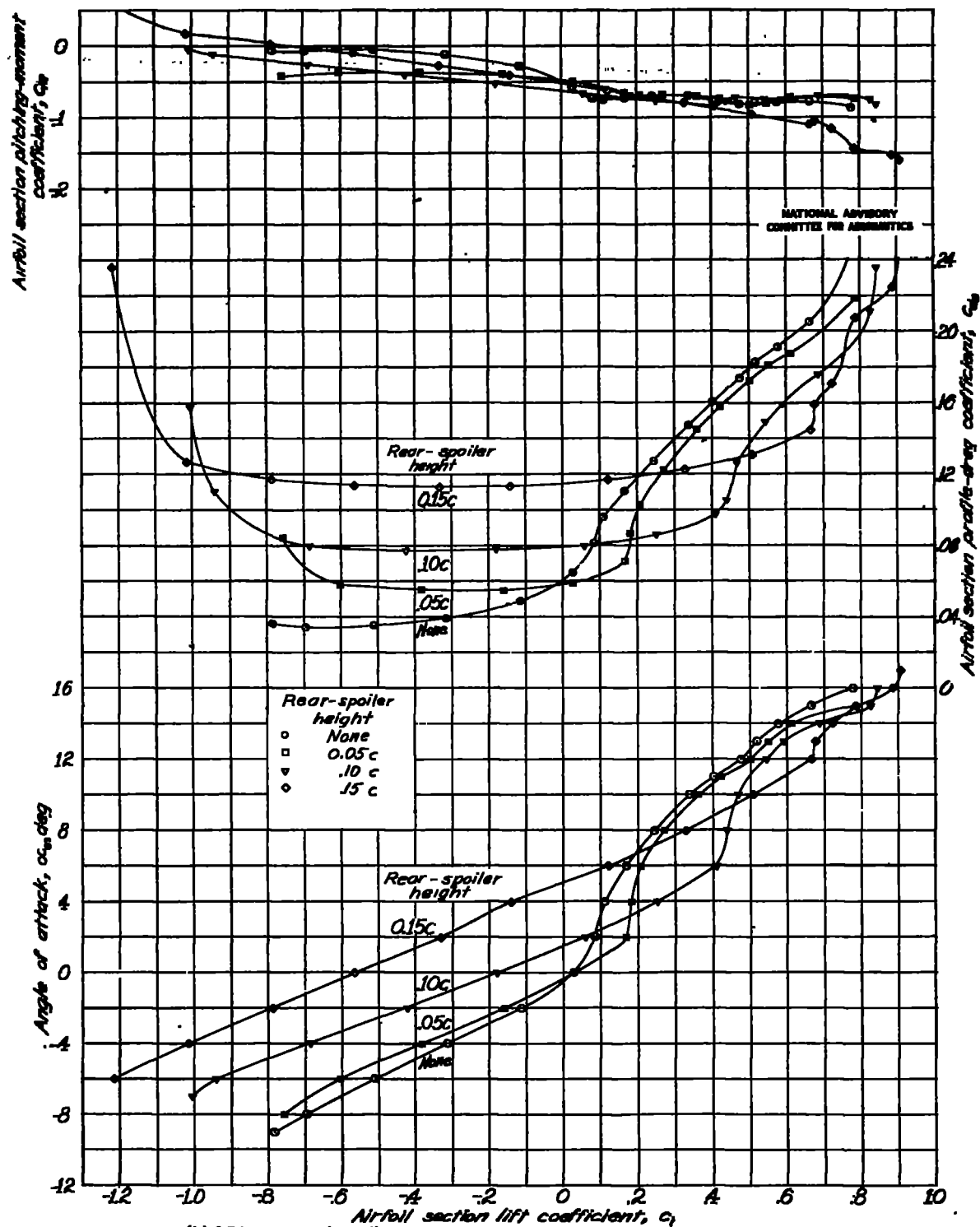
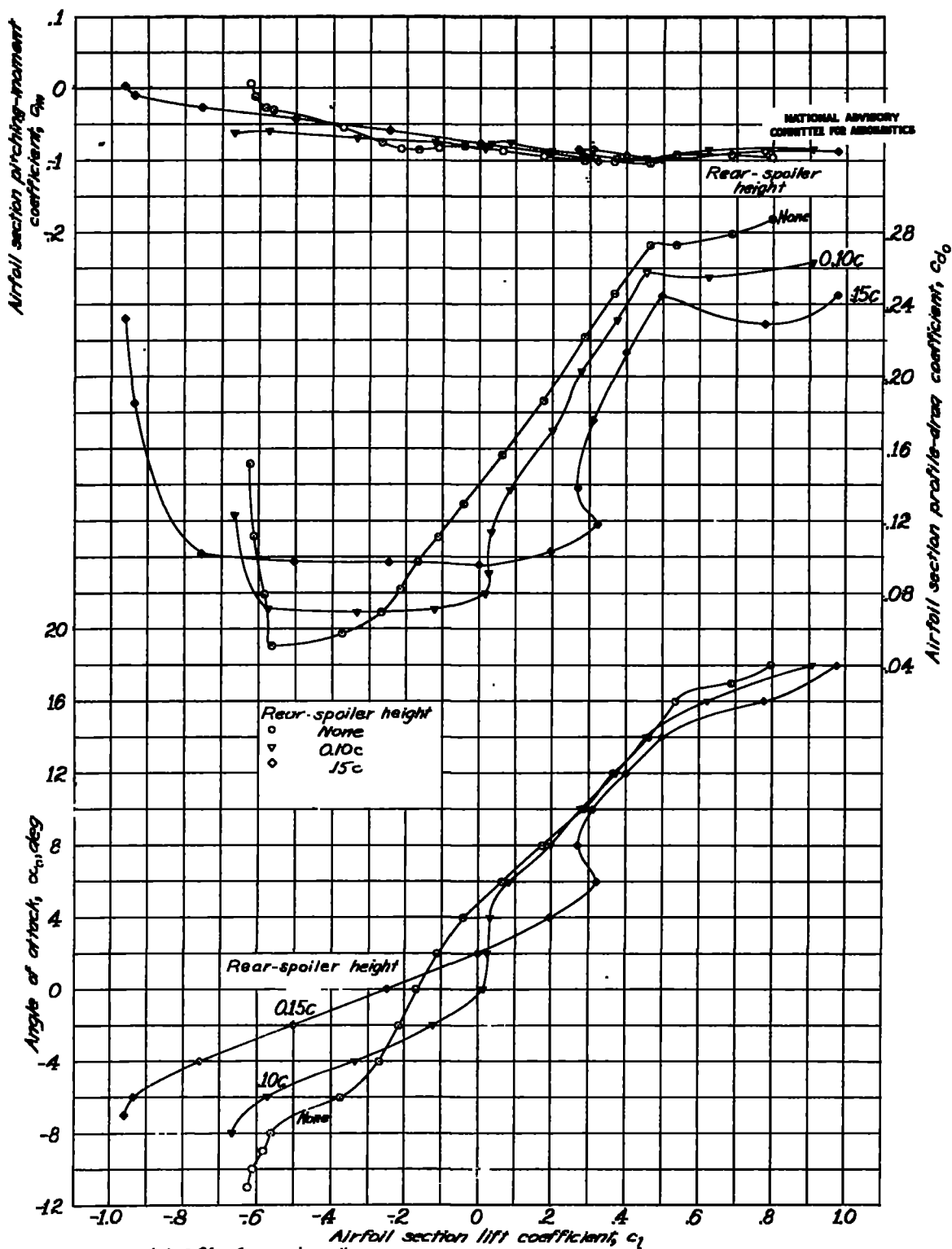


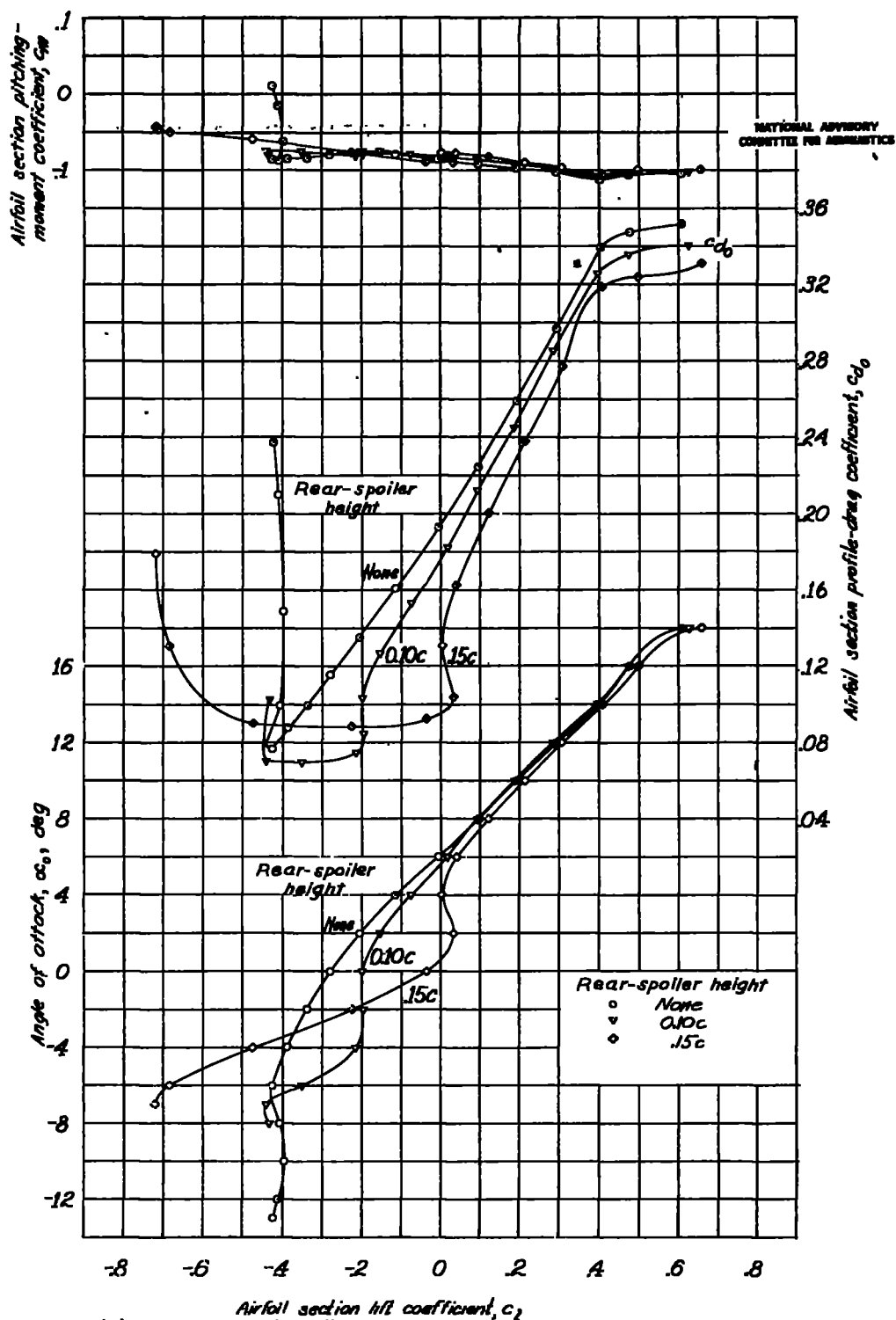
Figure 14.- Continued.

Fig. 14c

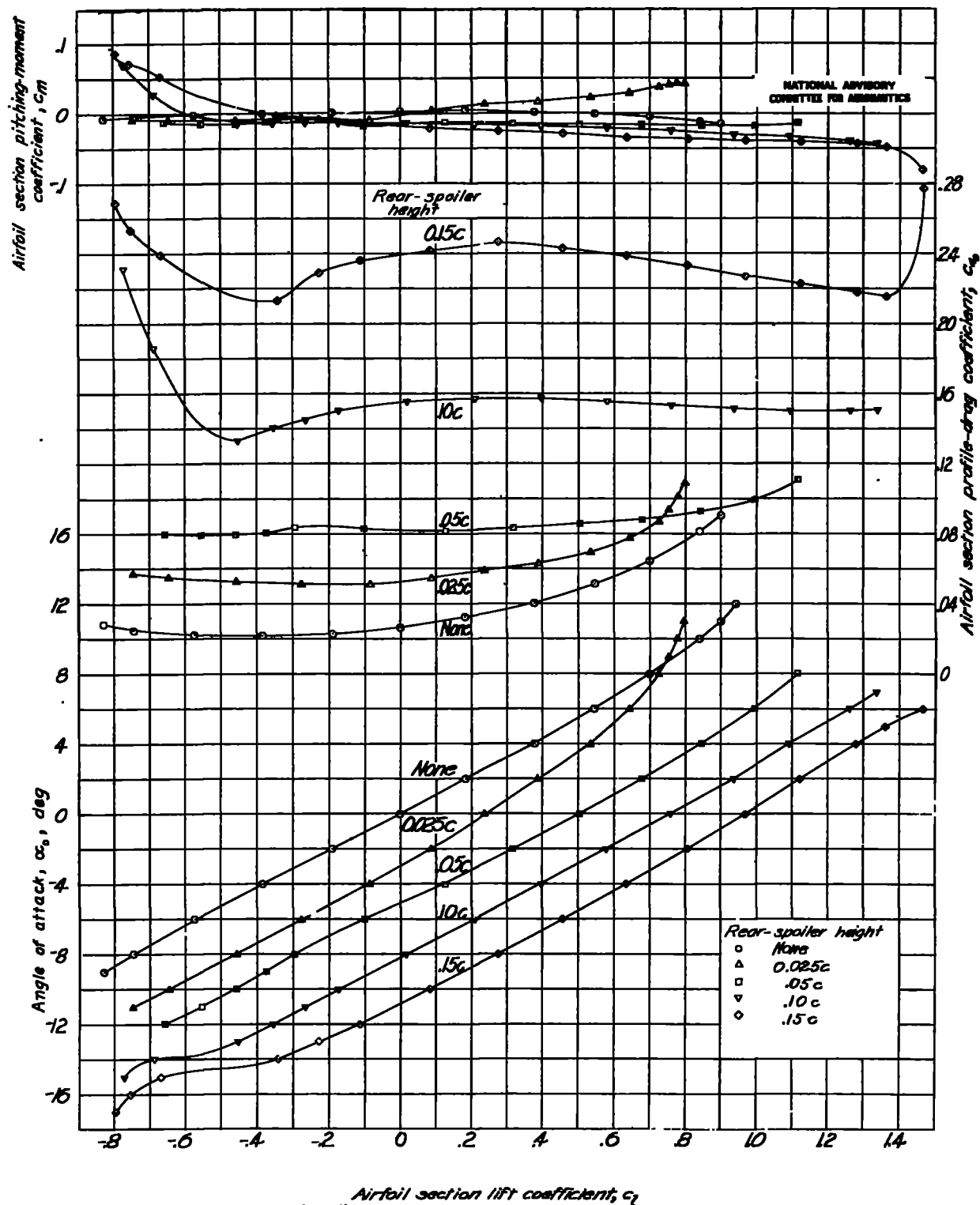
NACA ARR No. L5F28



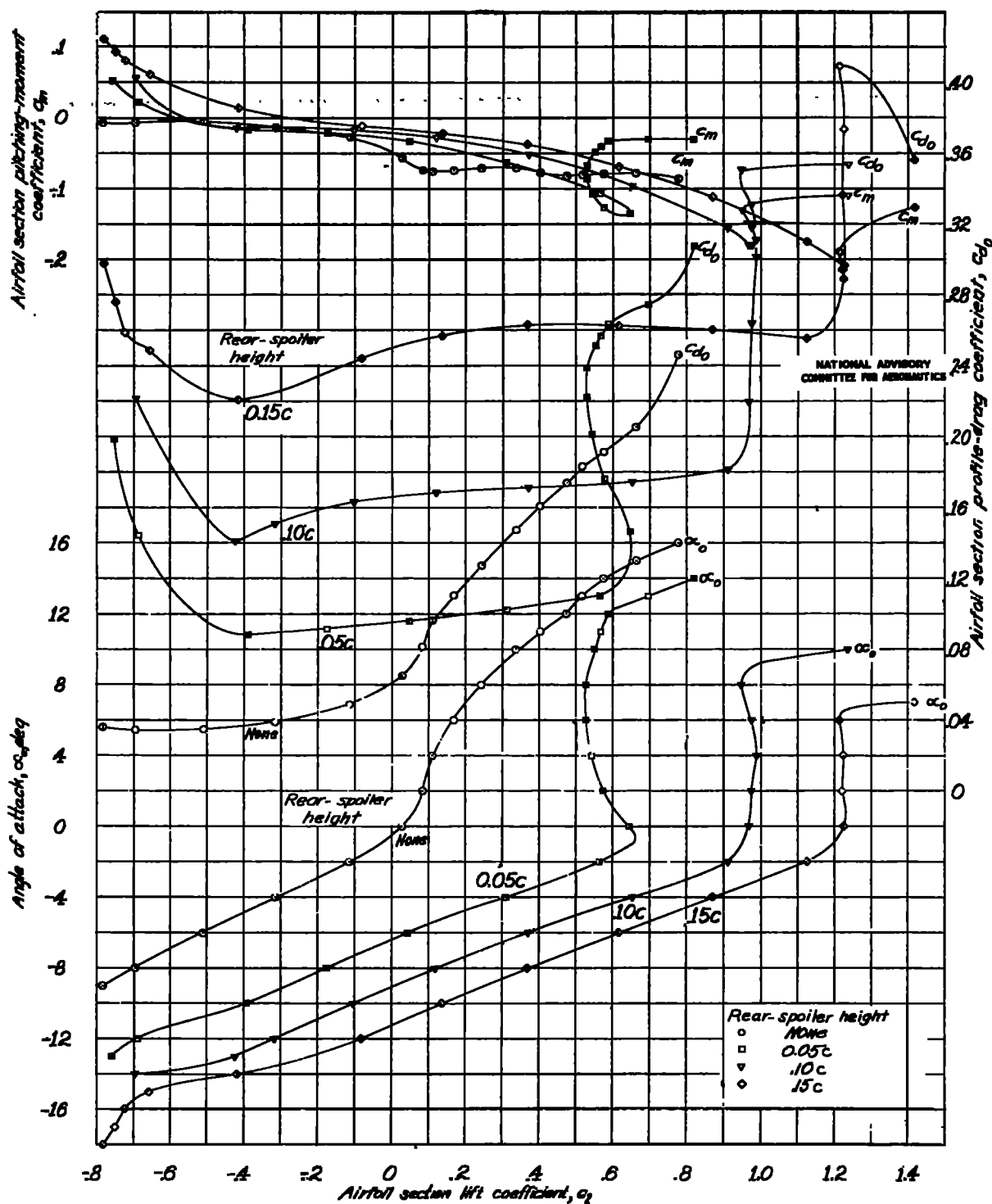
(c) 0.06c forward spoiler.
Figure 14.-Continued.



(d) 0.09c forward spoiler
 Figure 14.- Continued.



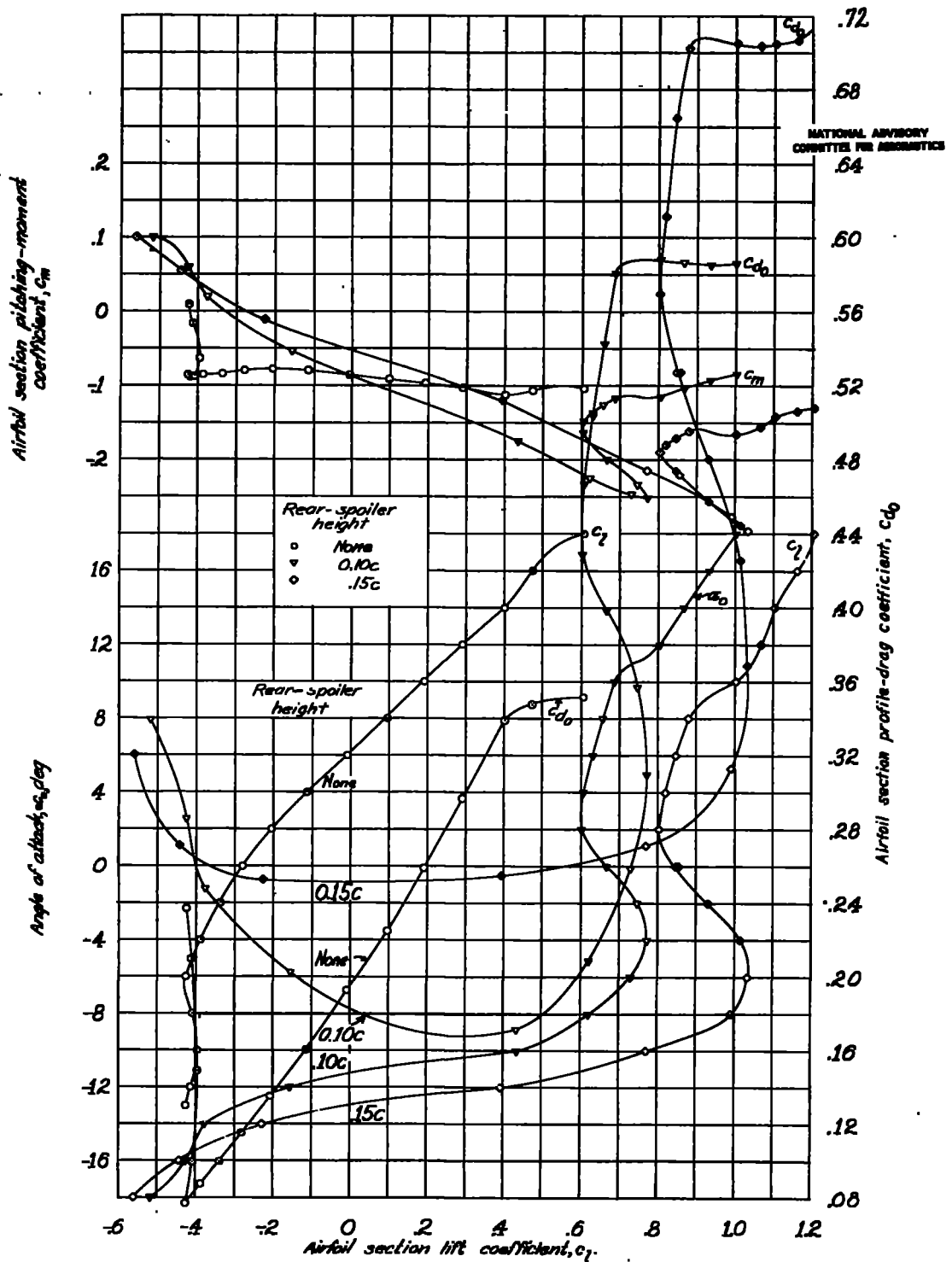
(a) 0.01c forward spoiler.
 Figure 15. Effect of rear-spoiler height on the aerodynamic section characteristics with a rear spoiler at 0.65c on lower surface and with a constant-height spoiler at 0.15c on upper surface of the airfoil; $\delta_1 = \delta_2 = 0^\circ$.



(b) 0.03c forward spoiler.
Figure 15.-Continued.

NACA ARR No. L5F28





(d) 0.09c forward spoiler.
Figure 15.-Concluded.

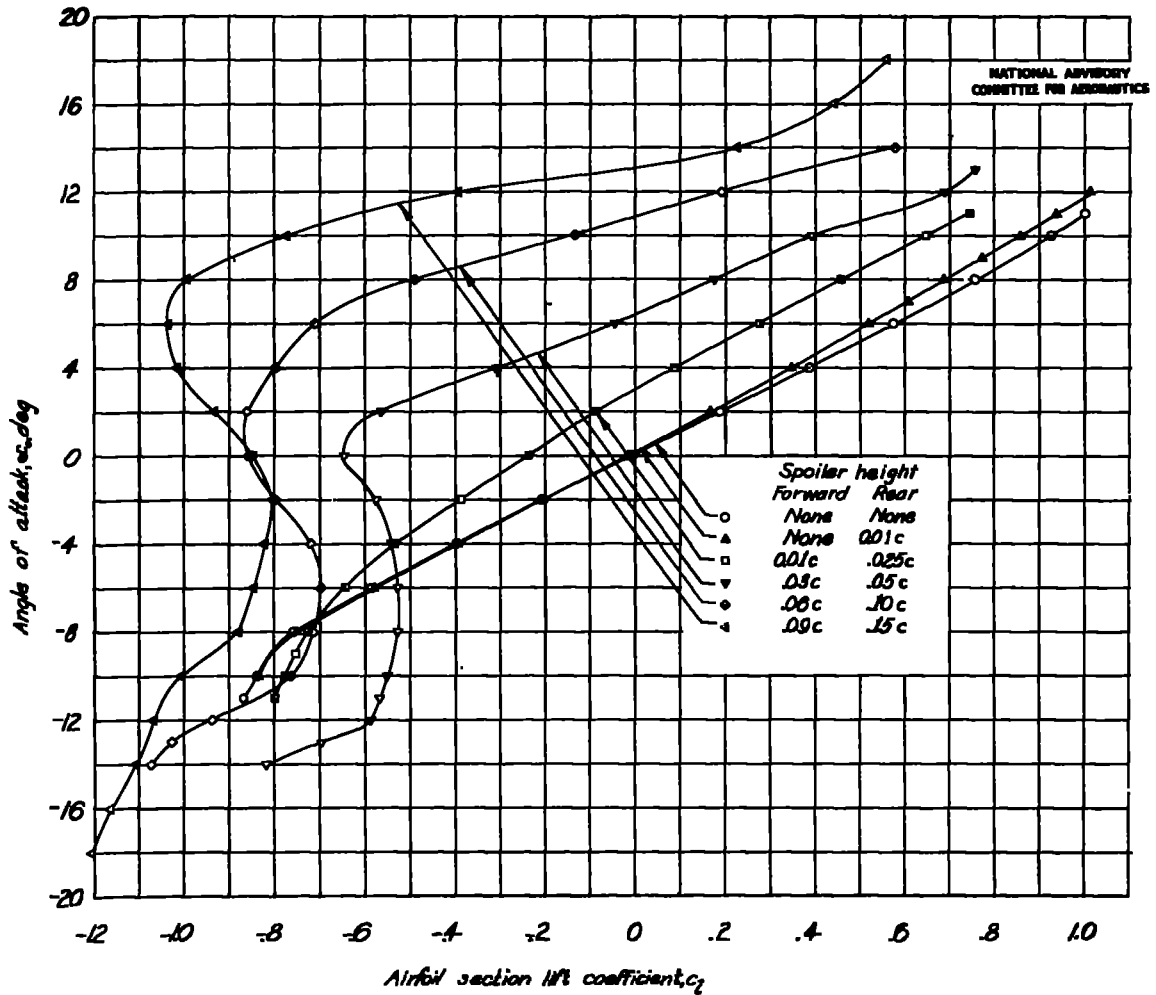


Figure 16. Effect of double spoilers on the aerodynamic section characteristics. Forward spoiler on the lower surface at 0.15c and rear spoiler on the upper surface at 0.65c; $\delta_f = \delta_r = 0^\circ$.

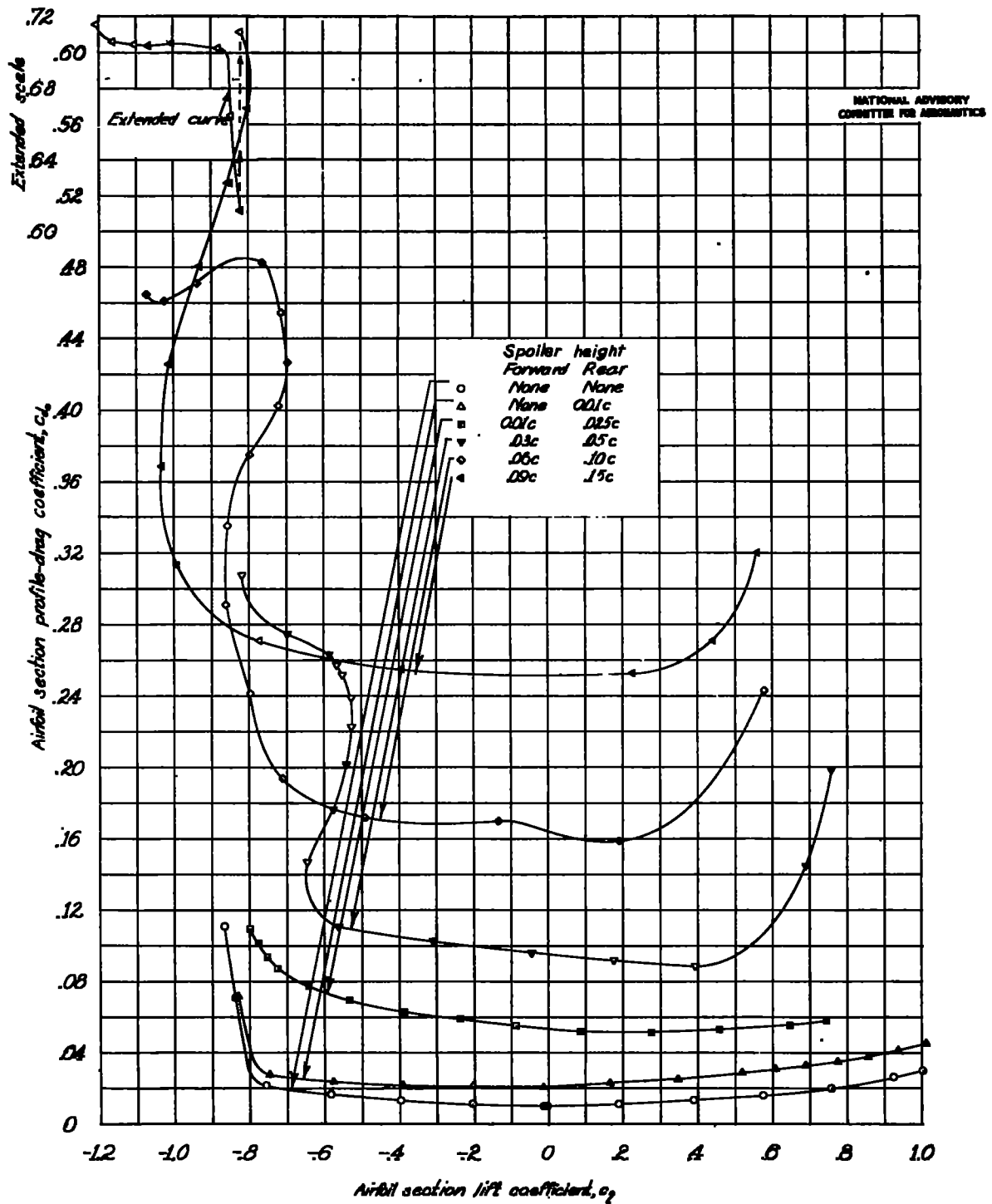


Figure 16.- Concluded.

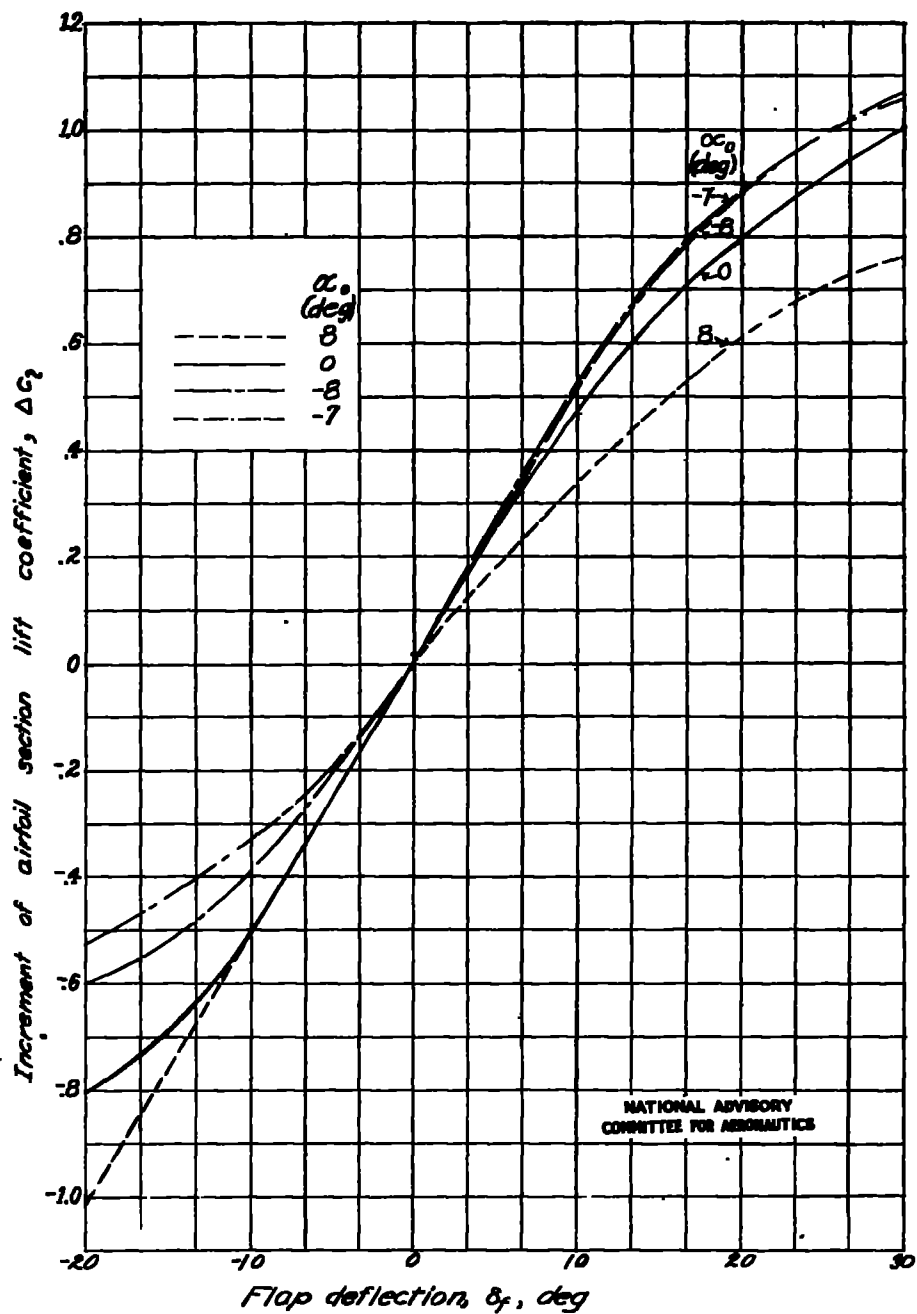


Figure 17: Effect of flap deflection on ΔC_L and ΔC_{h_f} with no spoilers on the plain airfoil.

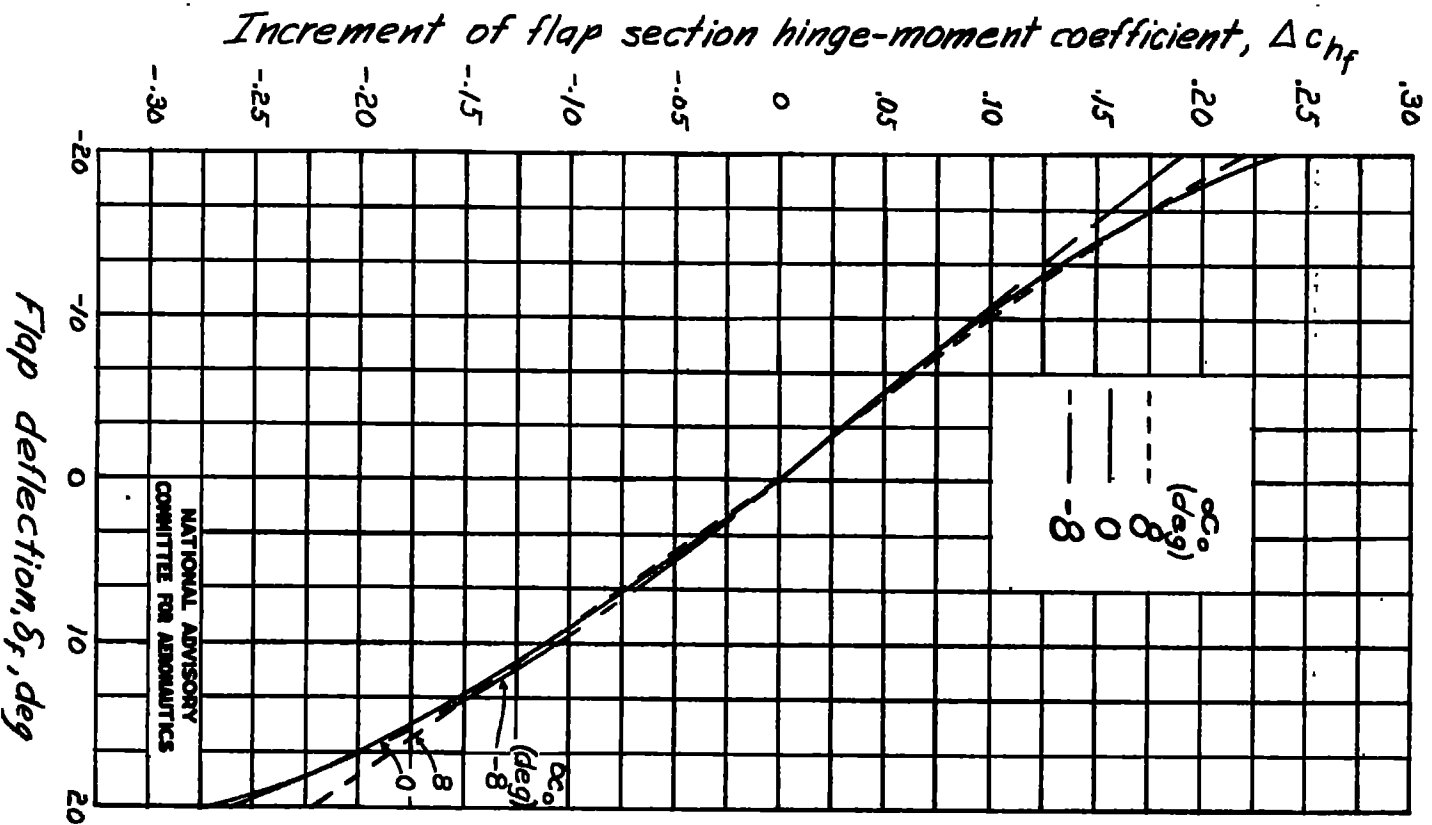


Figure 17.- Concluded.

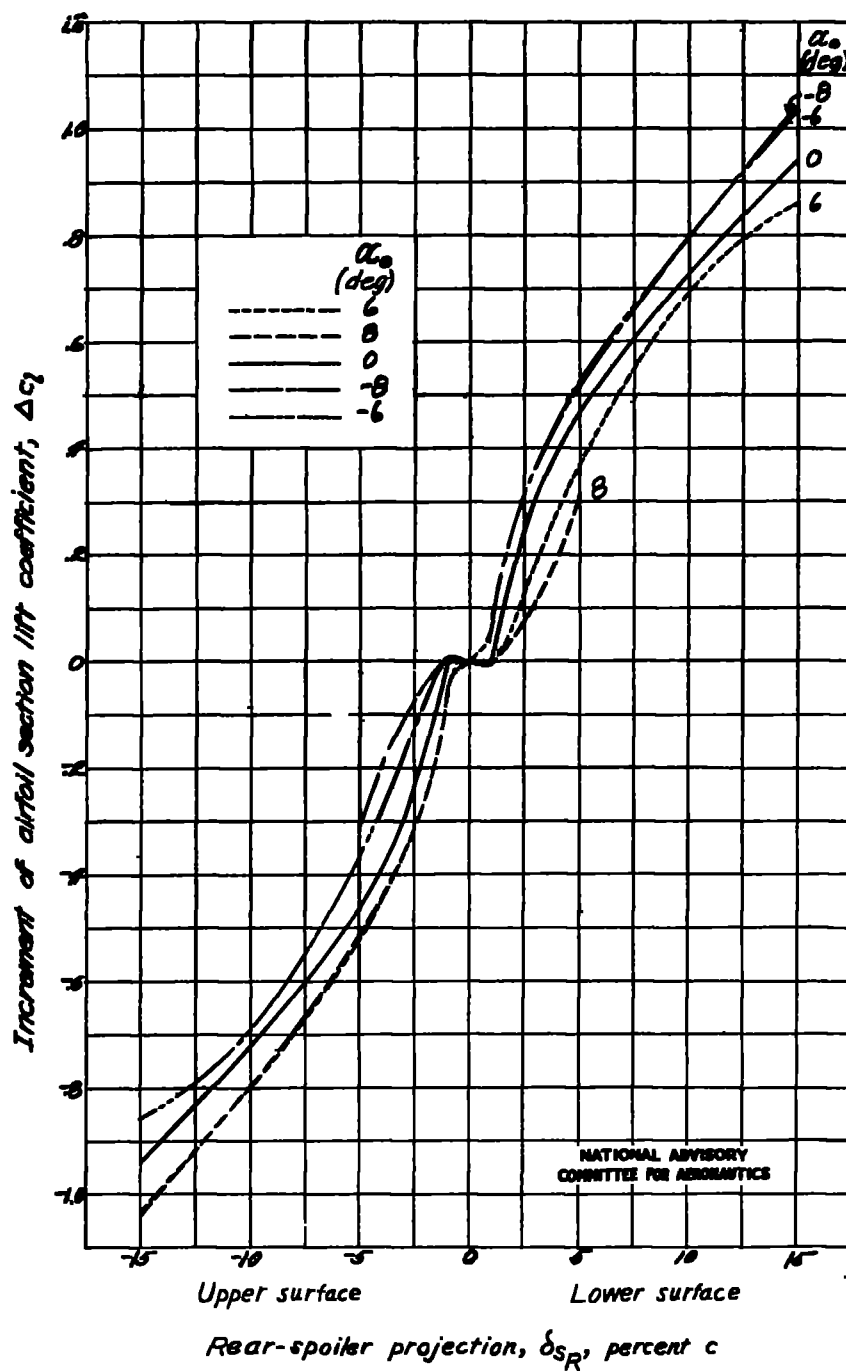


Figure 18.-Effect of rear-spoiler projection on ΔC_L . $\delta_f = \delta_t = 0^\circ$.

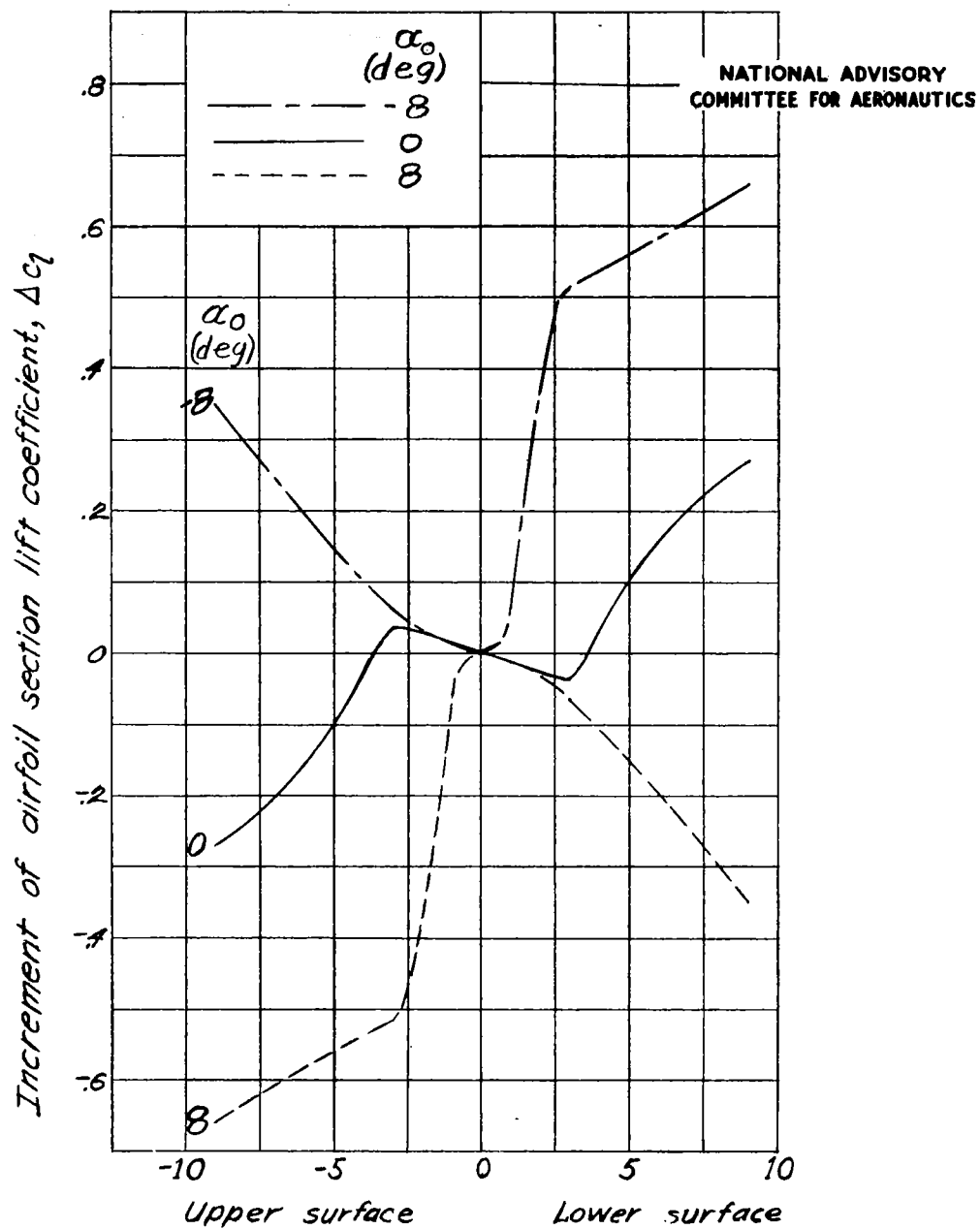
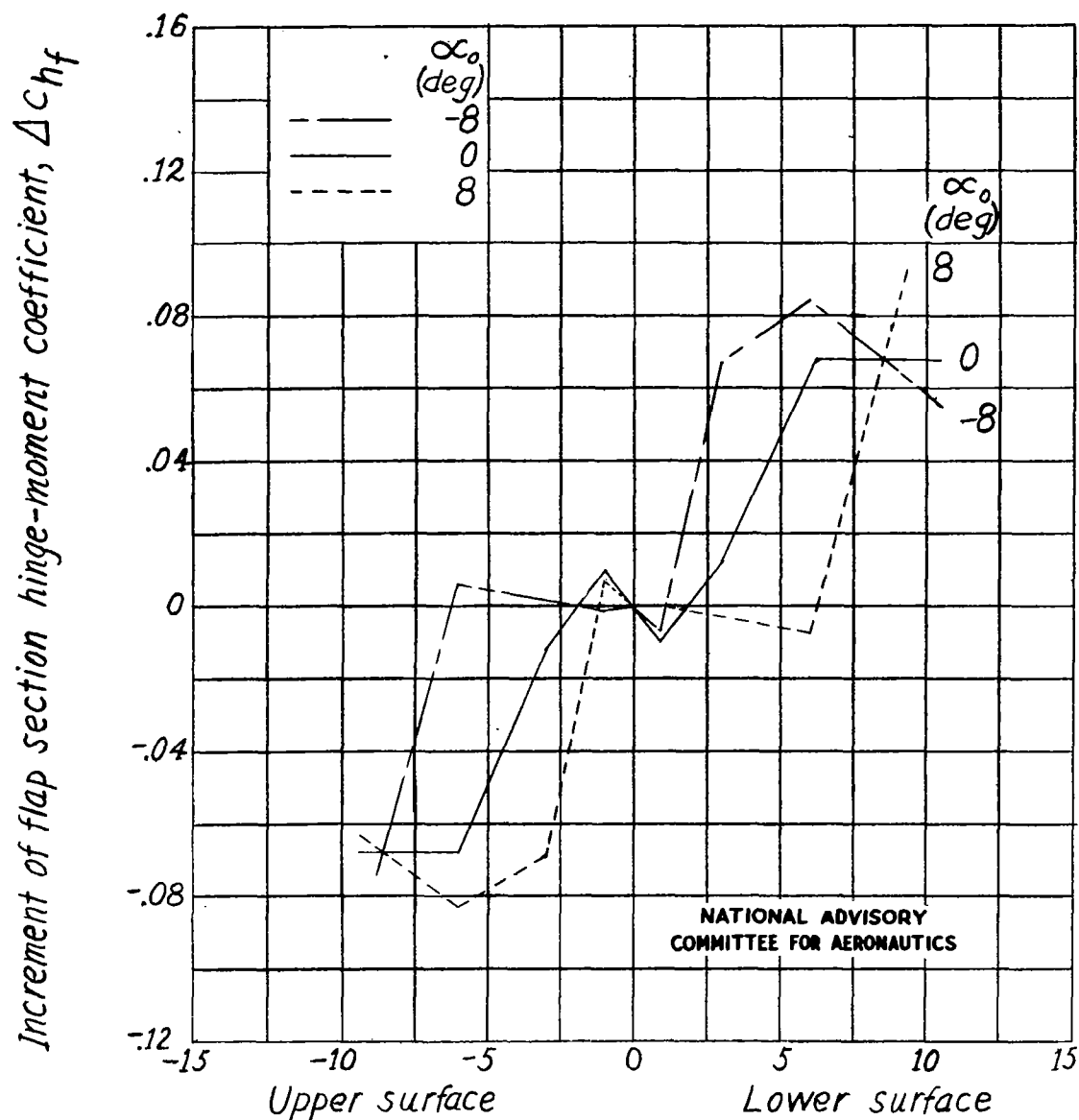


Figure 19.—Effect of forward-spoiler projection on Δc_l and Δc_{h_f} .
 $\delta_f = \delta_t = 0^\circ$



Forward-spoiler projection, δ_{SF} , percent c

Figure 19. - Concluded.

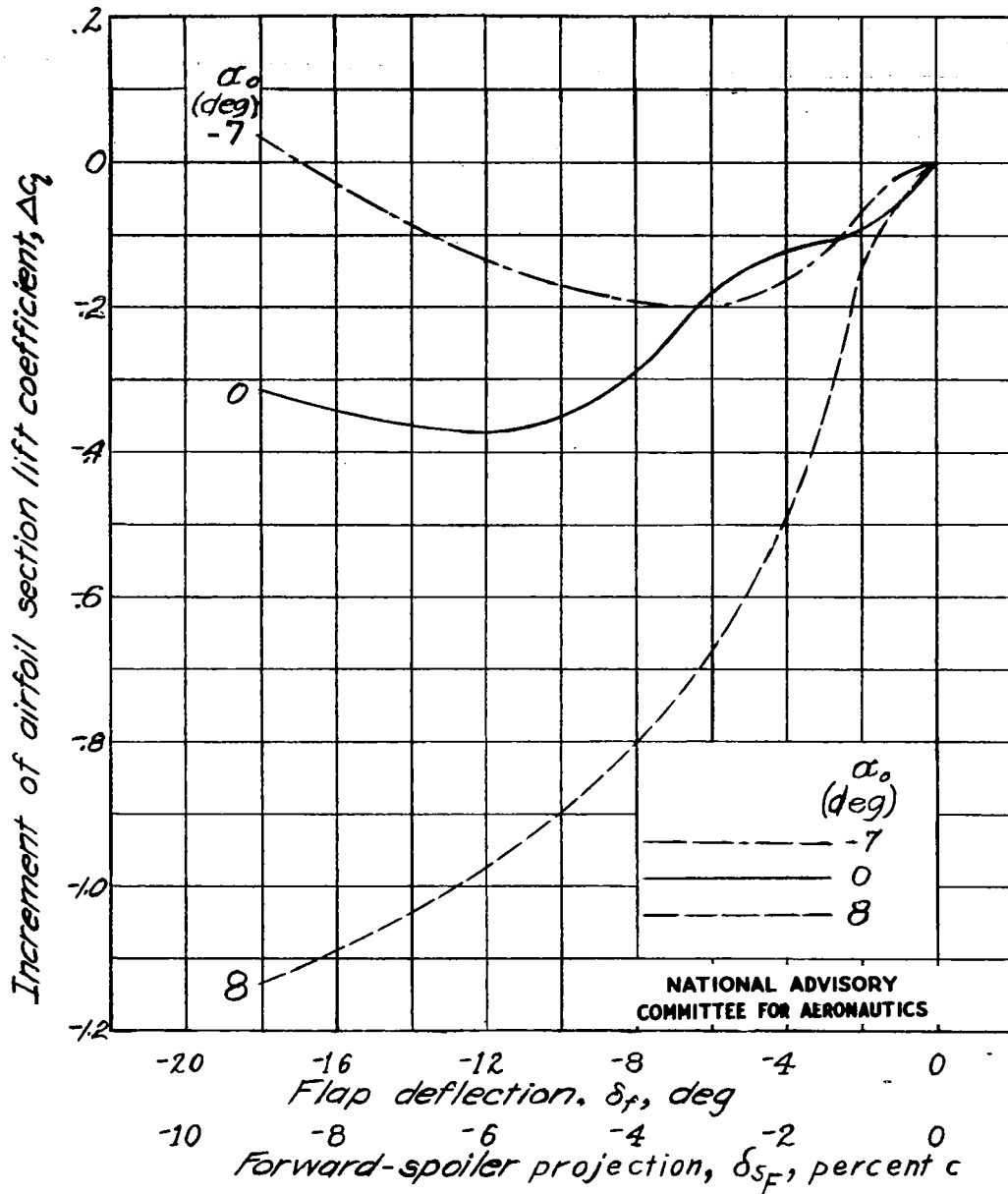


Figure 20.-Effect of forward-spoiler projection and flap deflection on ΔC_L with spoiler projecting $0.05c$ while flap deflects 10° ; spoiler on upper surface and flap deflecting upward.

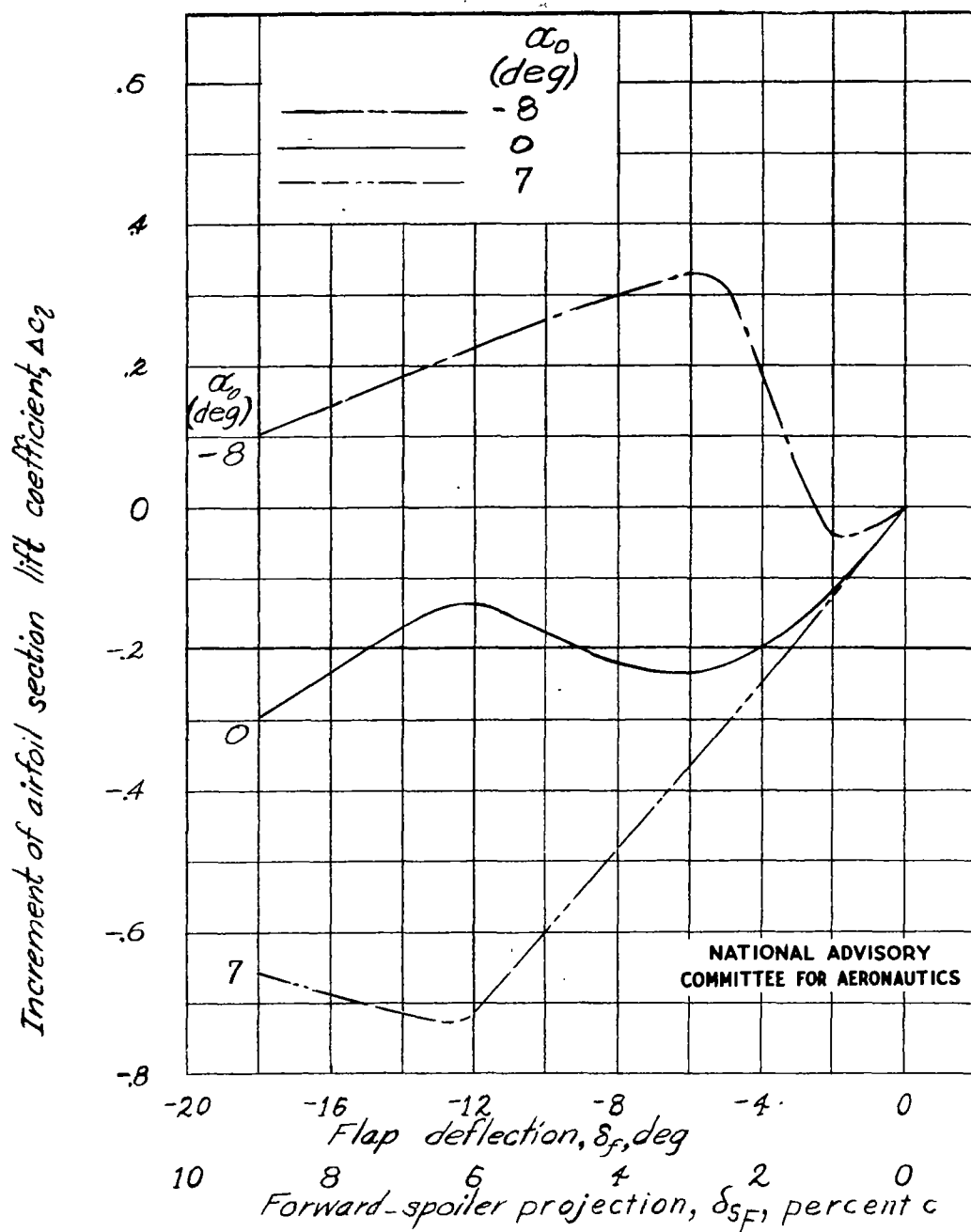
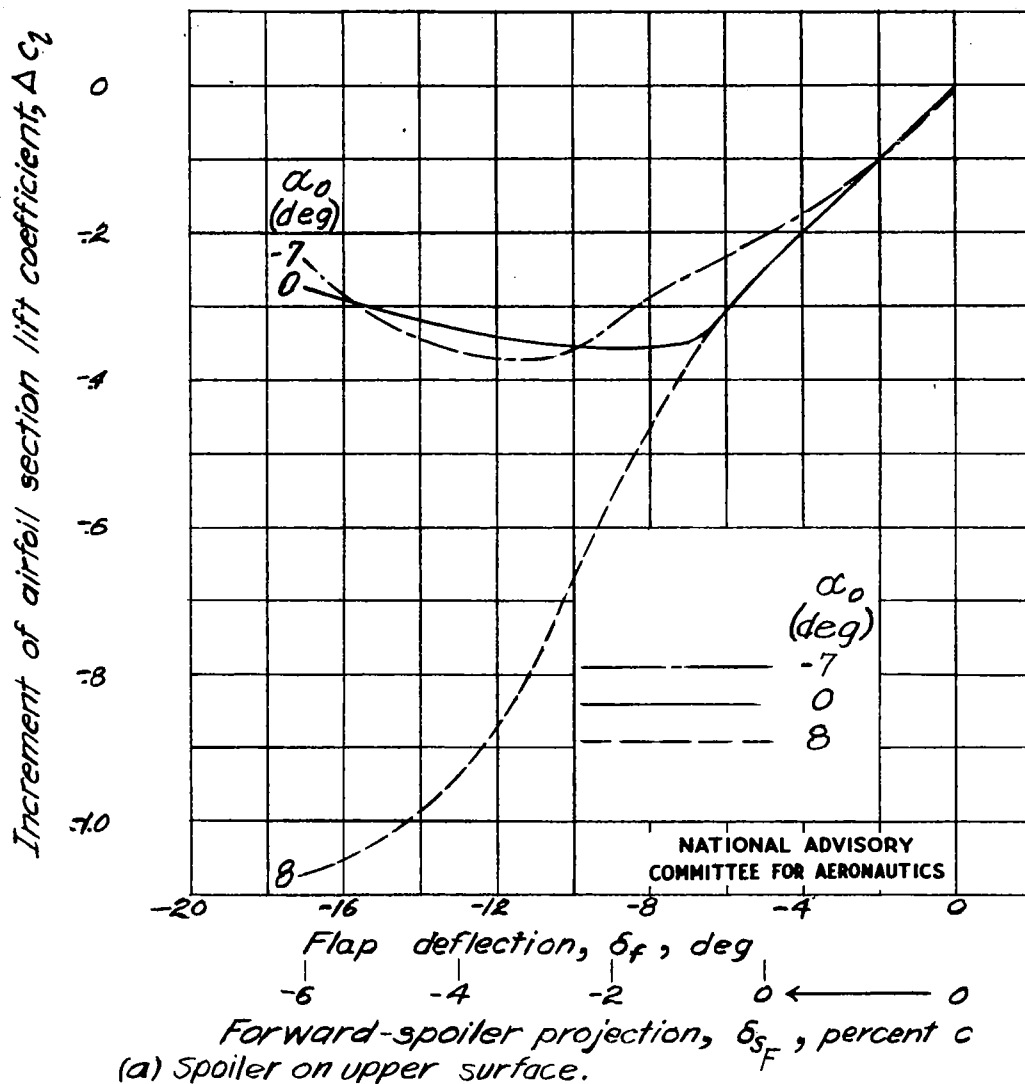
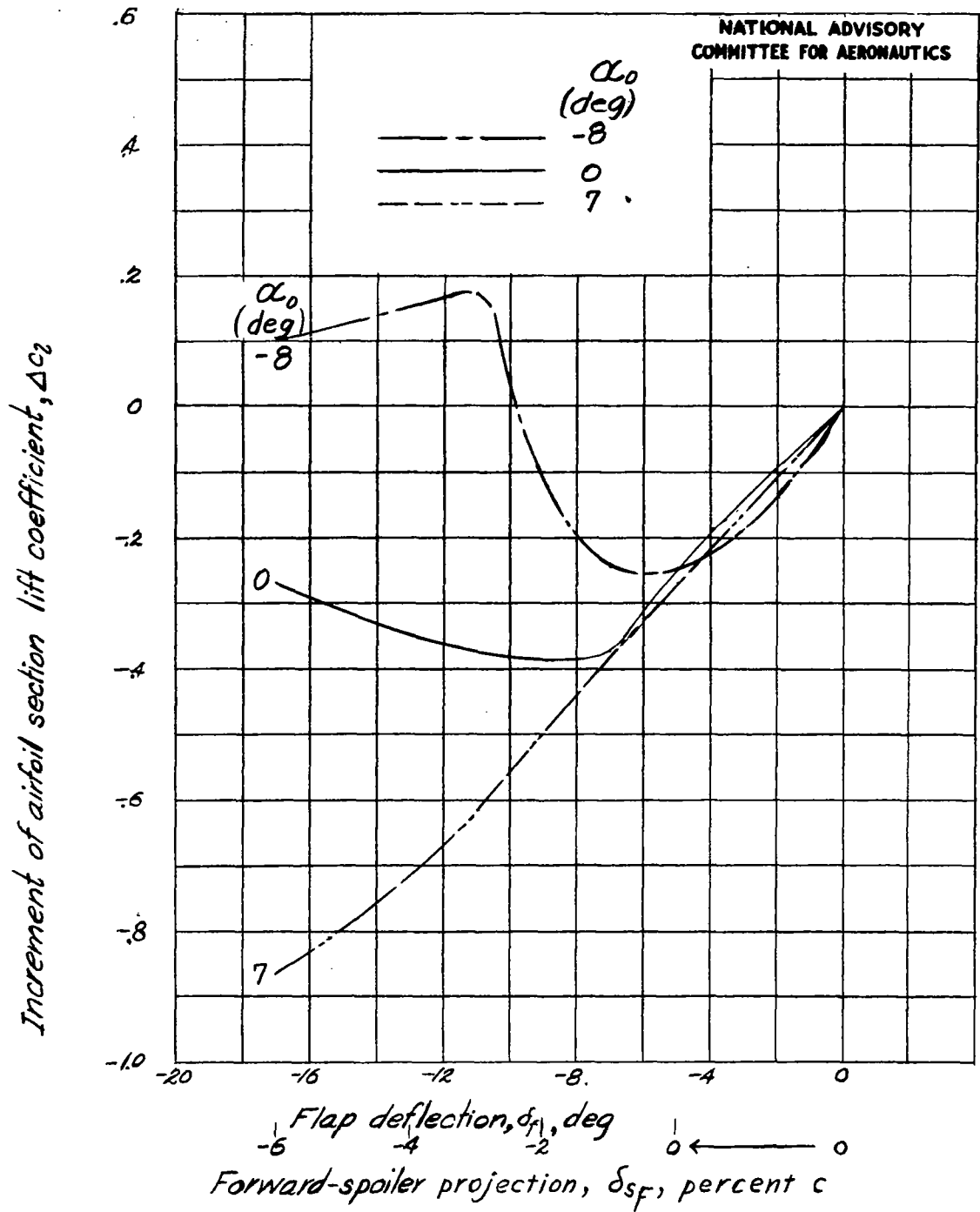


Figure 21. Effect of forward-spoiler projection and flap deflection on Δc_l with spoiler projecting 0.05c while flap deflects 10°. Spoiler on lower surface and flap deflecting upward.



(a) Spoiler on upper surface.

Figure 22. -Effect of forward-spoiler projection and flap deflection on ΔC_L with flap deflected alone to -5° and then spoiler projecting 0.05c for every 10° of flap deflection. Flap deflecting upward.



(b) Spoiler on lower surface.
Figure 22.- Concluded.

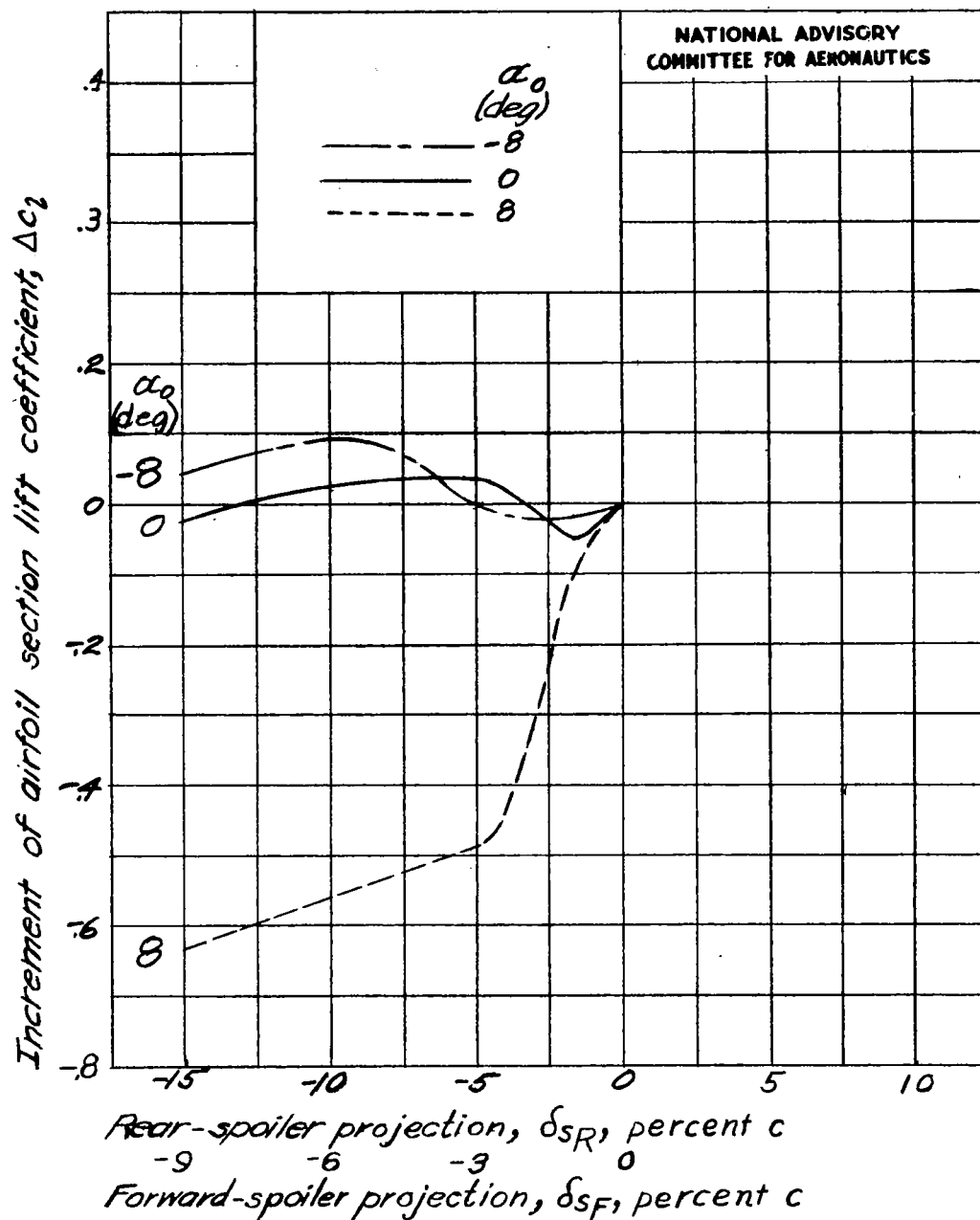


Figure 23.-Effect of a combination of forward and rear spoilers on upper surface. Forward-spoiler projection equals three-fifths rear-spoiler projection.

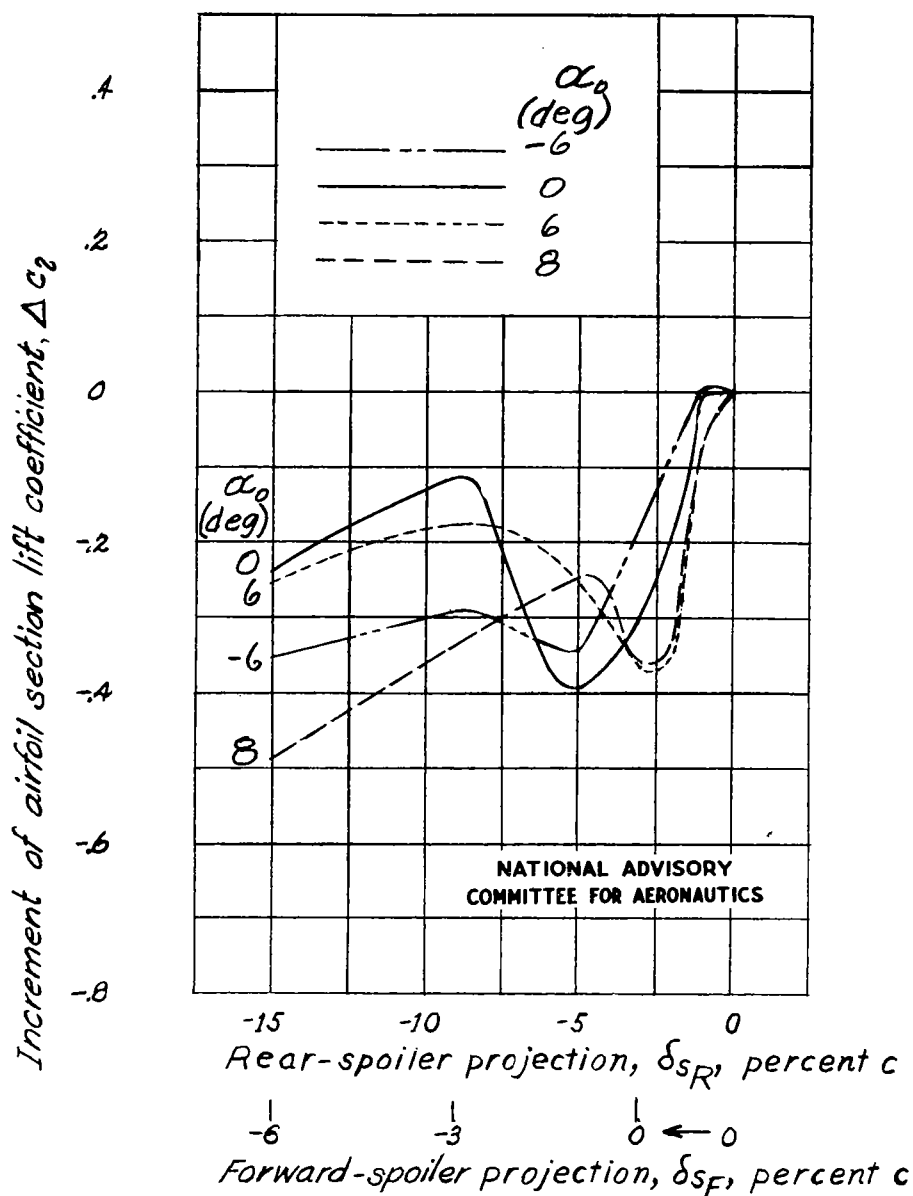


Figure 24.—Effect of a combination of spoilers, both forward and rear spoilers on upper surface with movements as follows: rear spoiler alone to $0.03c$; forward spoiler then projecting one-half as fast as rear spoiler.

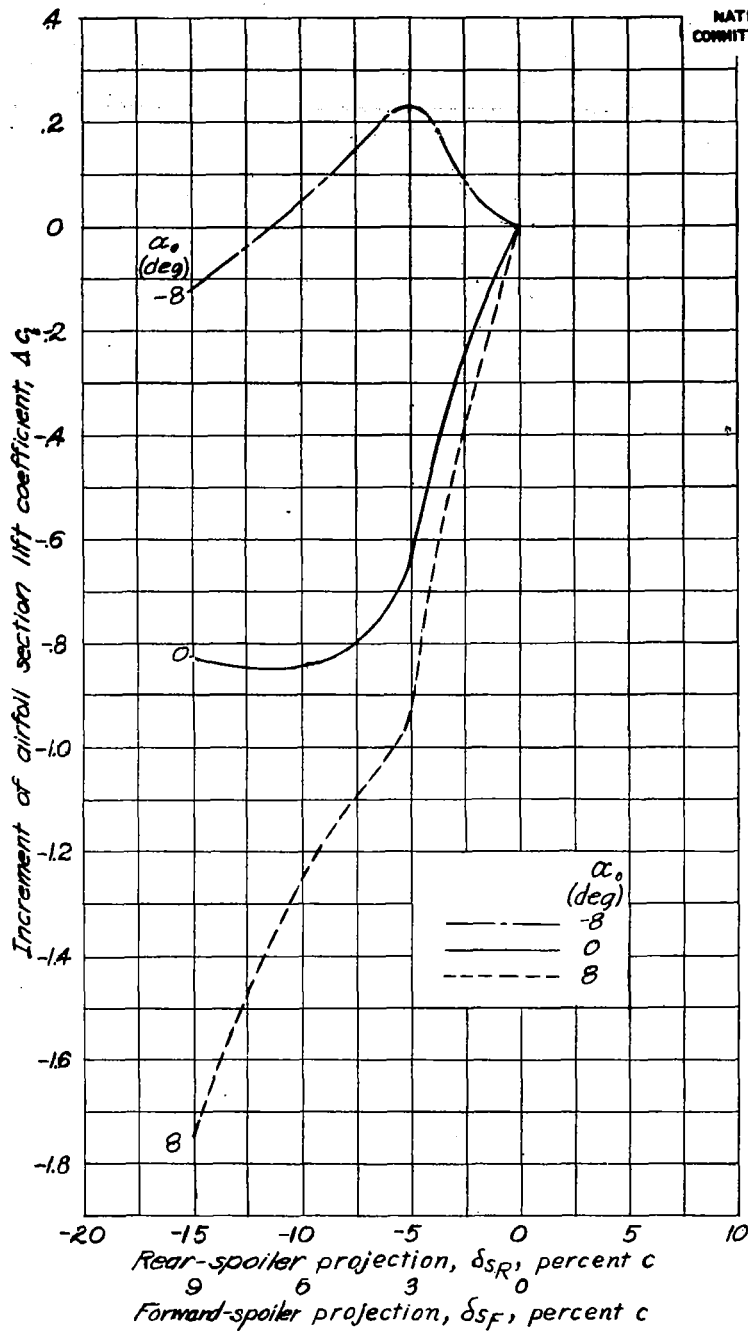


Figure 25.-Effect of a combination of spoilers. Forward-spoiler projection always equal to three-fifths rear-spoiler projection; rear spoiler on upper surface; forward spoiler on lower surface.

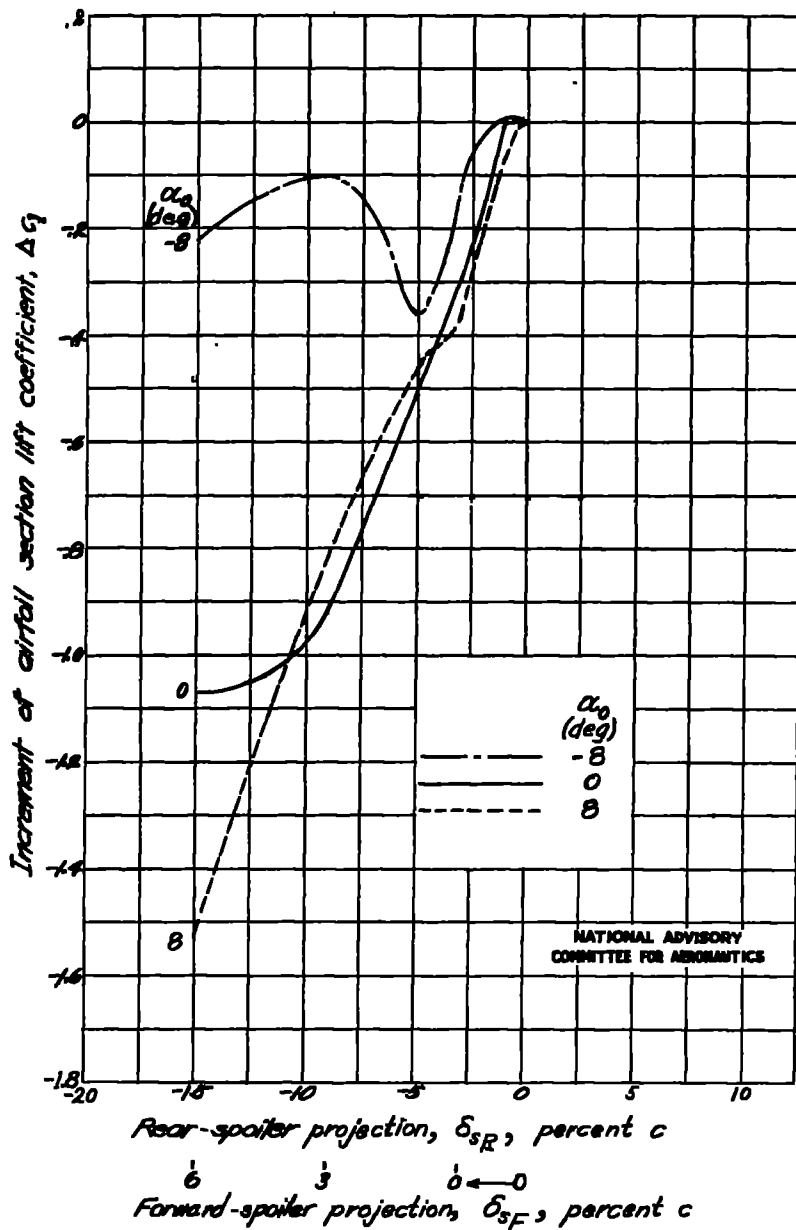


Figure 26.-Effect of a combination of spoilers. Rear spoiler on upper surface; forward spoiler on lower surface with following movements: rear spoiler alone to $-0.03c$; forward spoiler then projecting one-half as fast as rear spoiler.

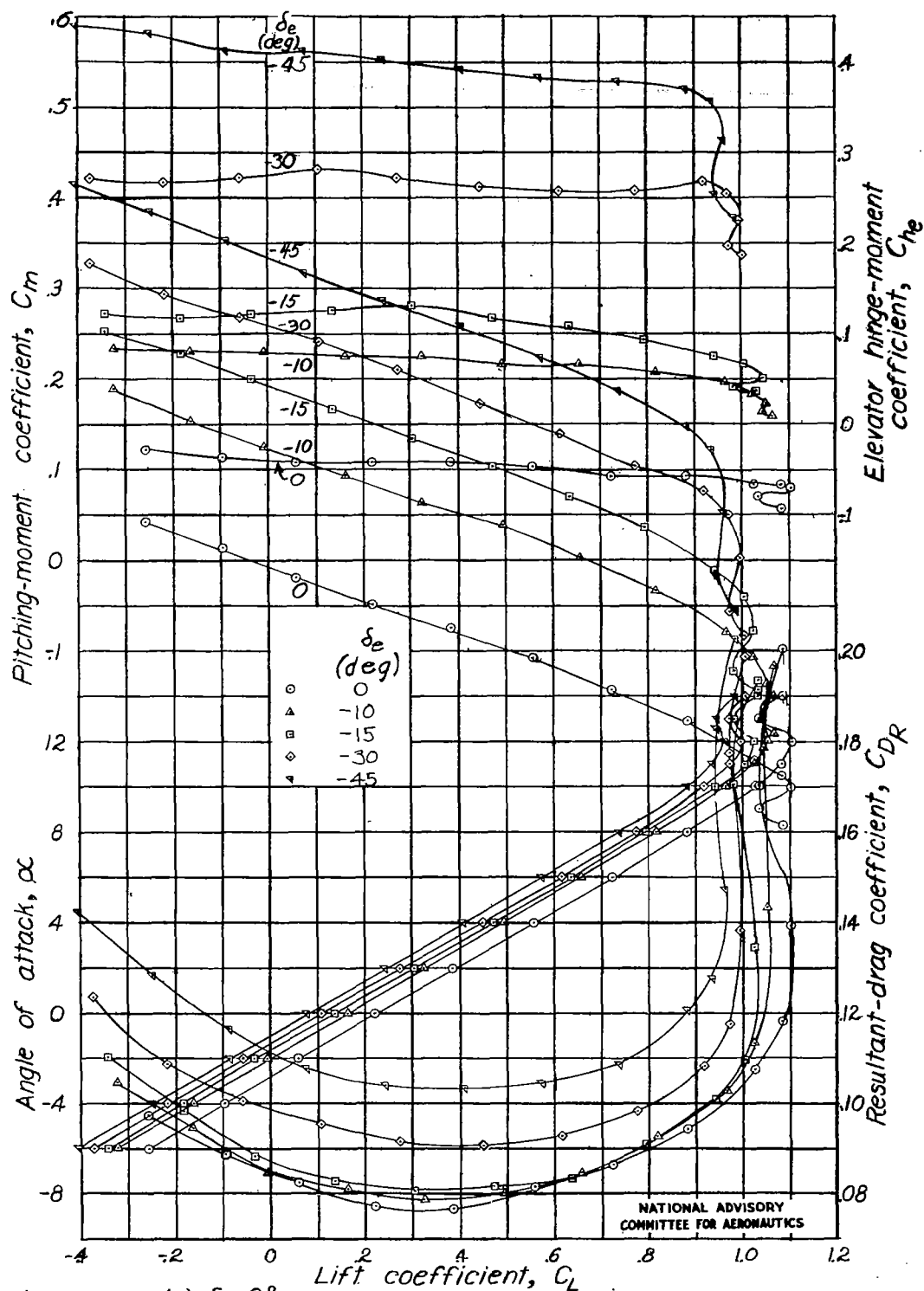
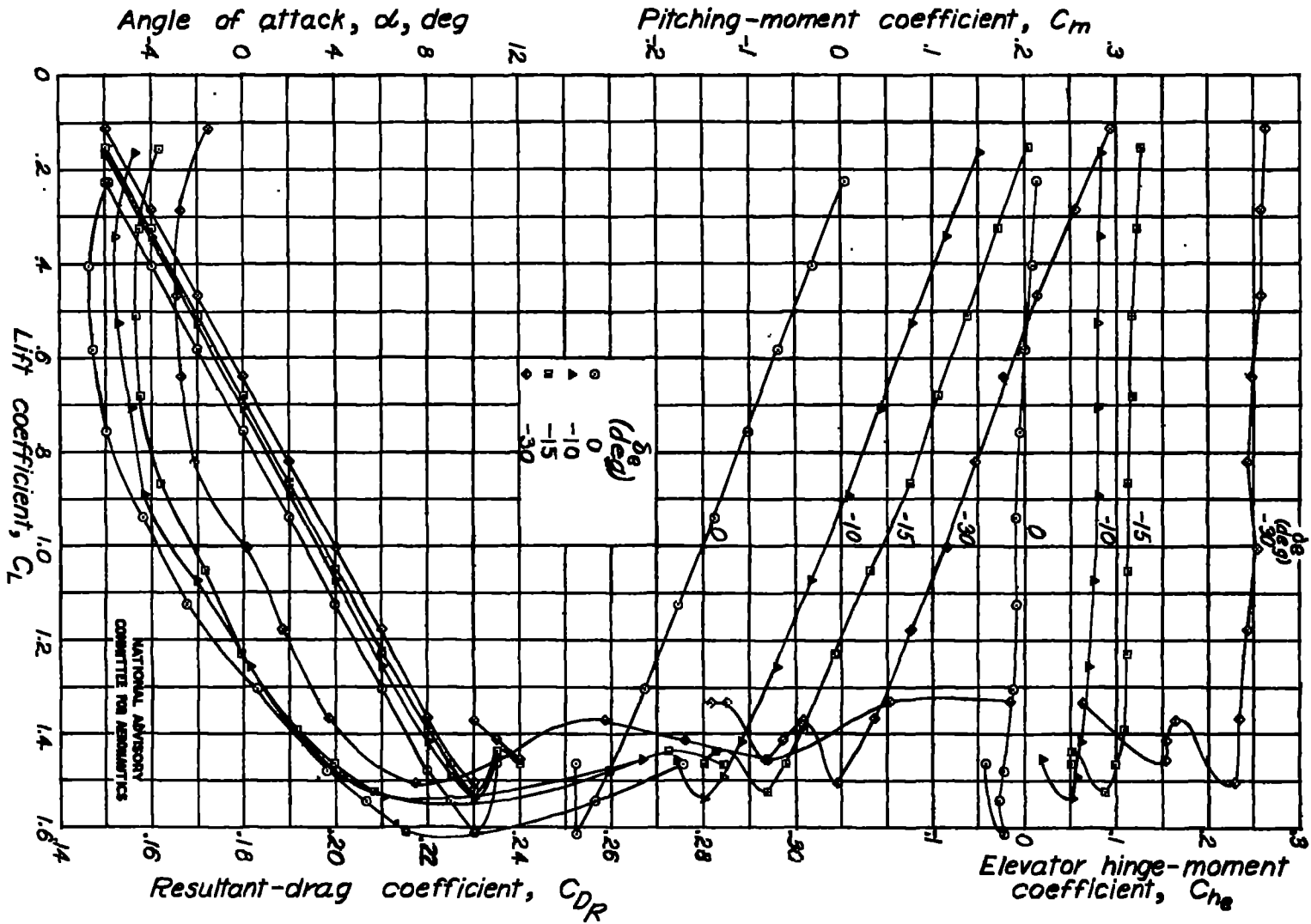


Figure 27-Effect of elevator deflection on aerodynamic characteristics of model A near ground board.



(b) $\delta_e = 45^\circ$
Figure 27.- Concluded.

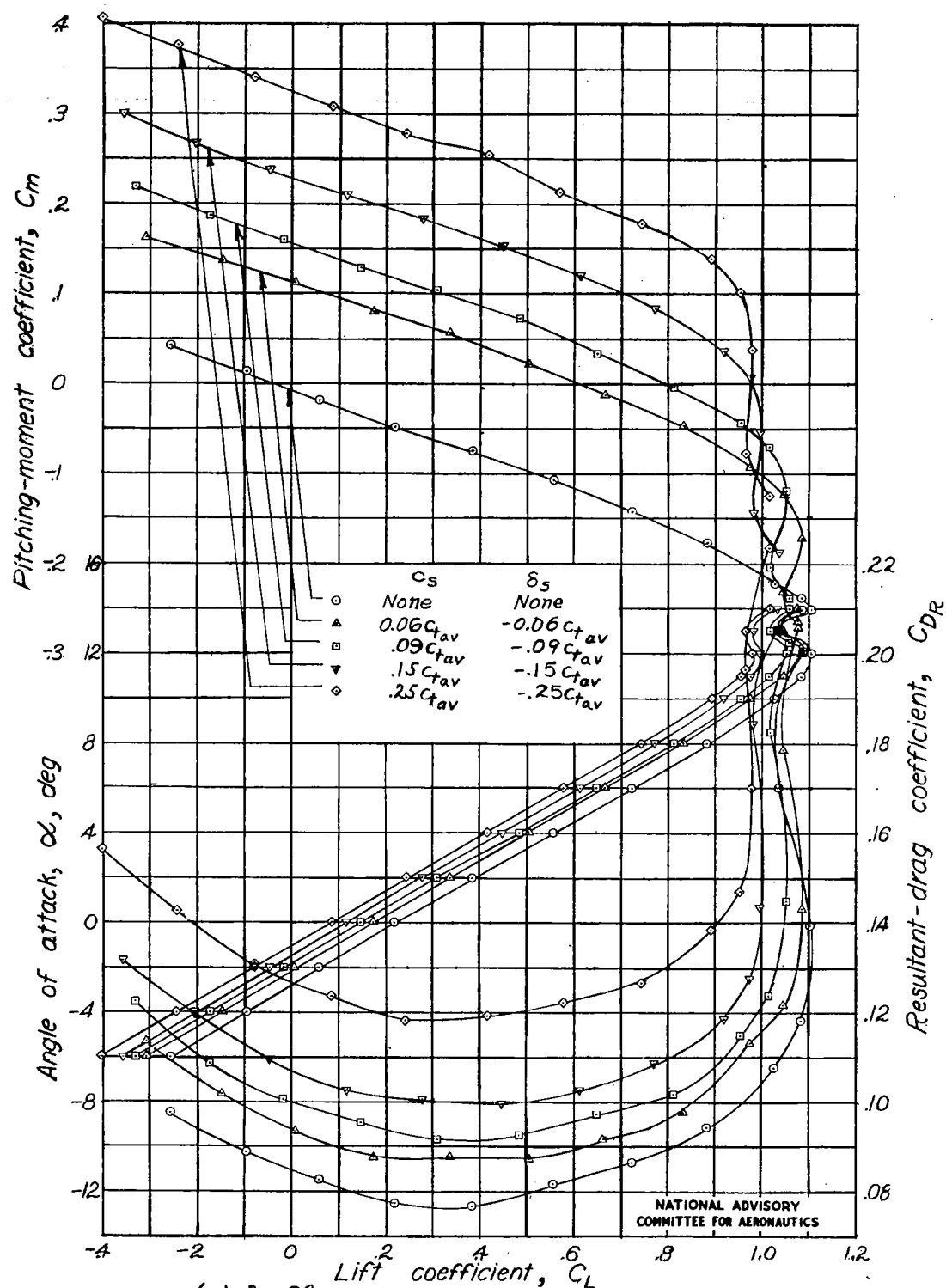
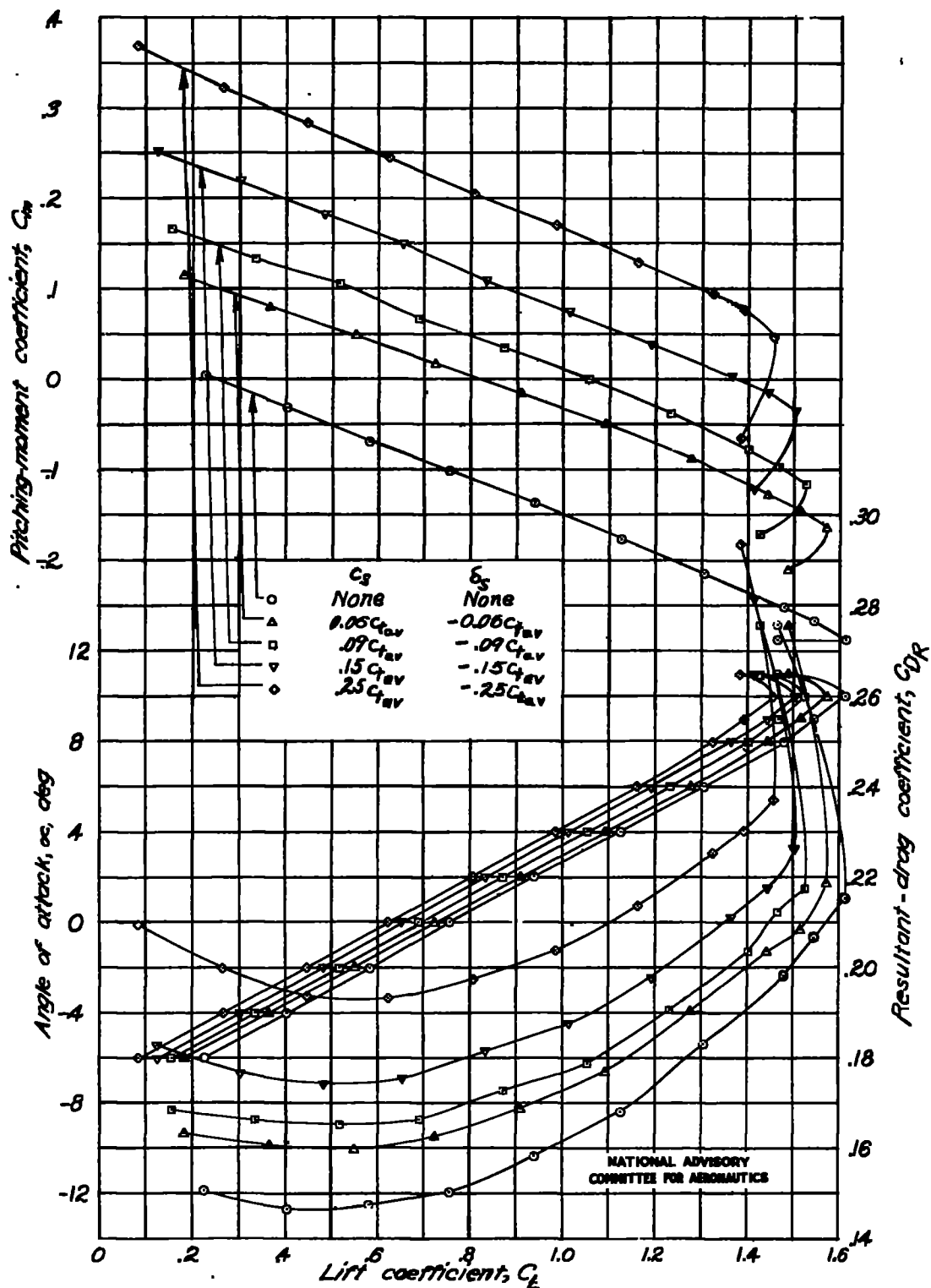


Figure 28.-Effect of spoiler projection on aerodynamic characteristics of model A near ground board. $\delta_e = 0^\circ$. Spoiler at hinge line on upper surface.



(b) $\delta_p = 45^\circ$
Figure 28. - Concluded.

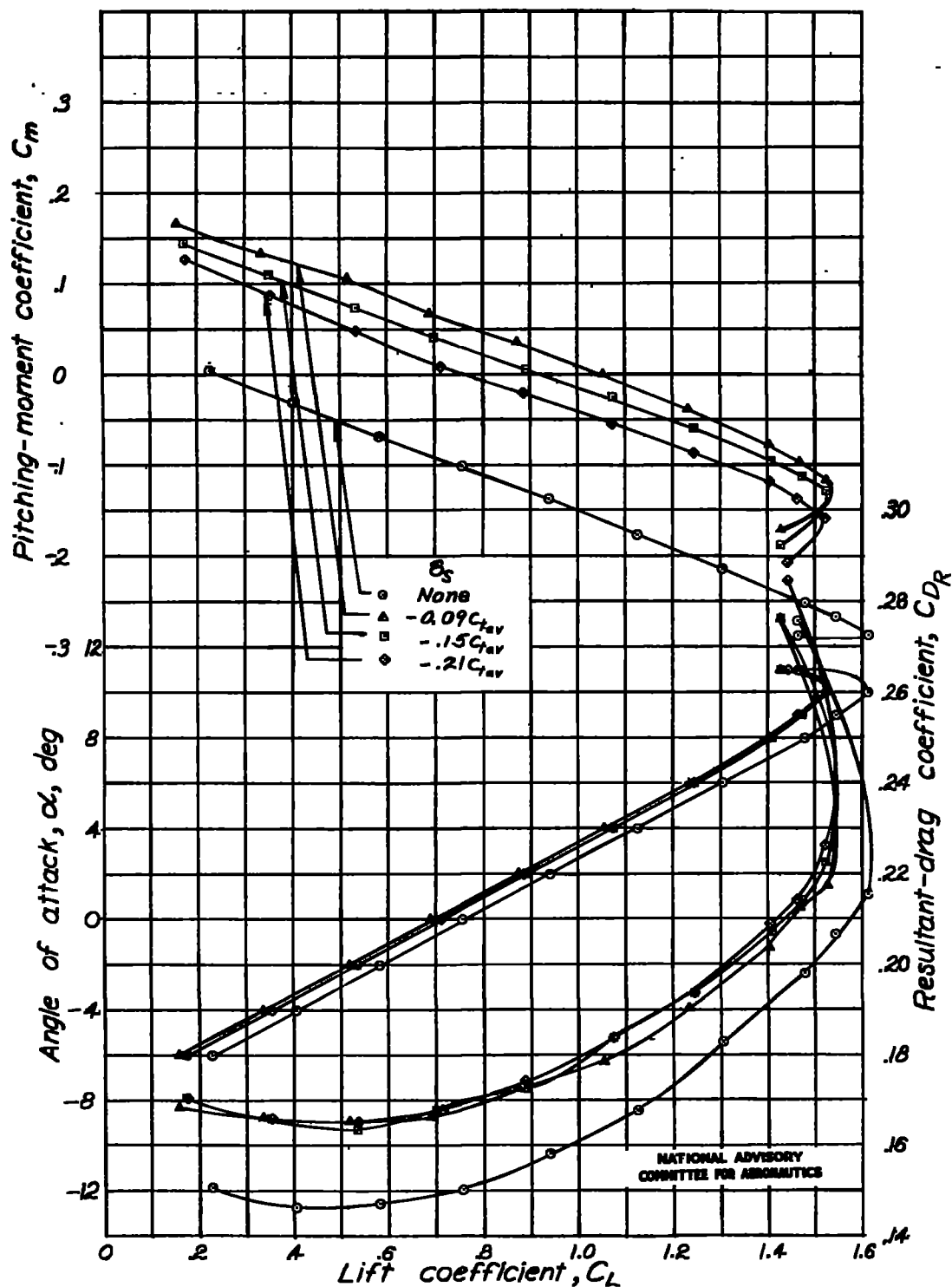


Figure 29.-Effect of spoiler gap on the aerodynamic characteristics of model A near ground board. $c_s = 0.09c_{tav}$; $\delta_f = 45^\circ$; $\delta_c = 0^\circ$; spoiler at hinge line on upper surface.

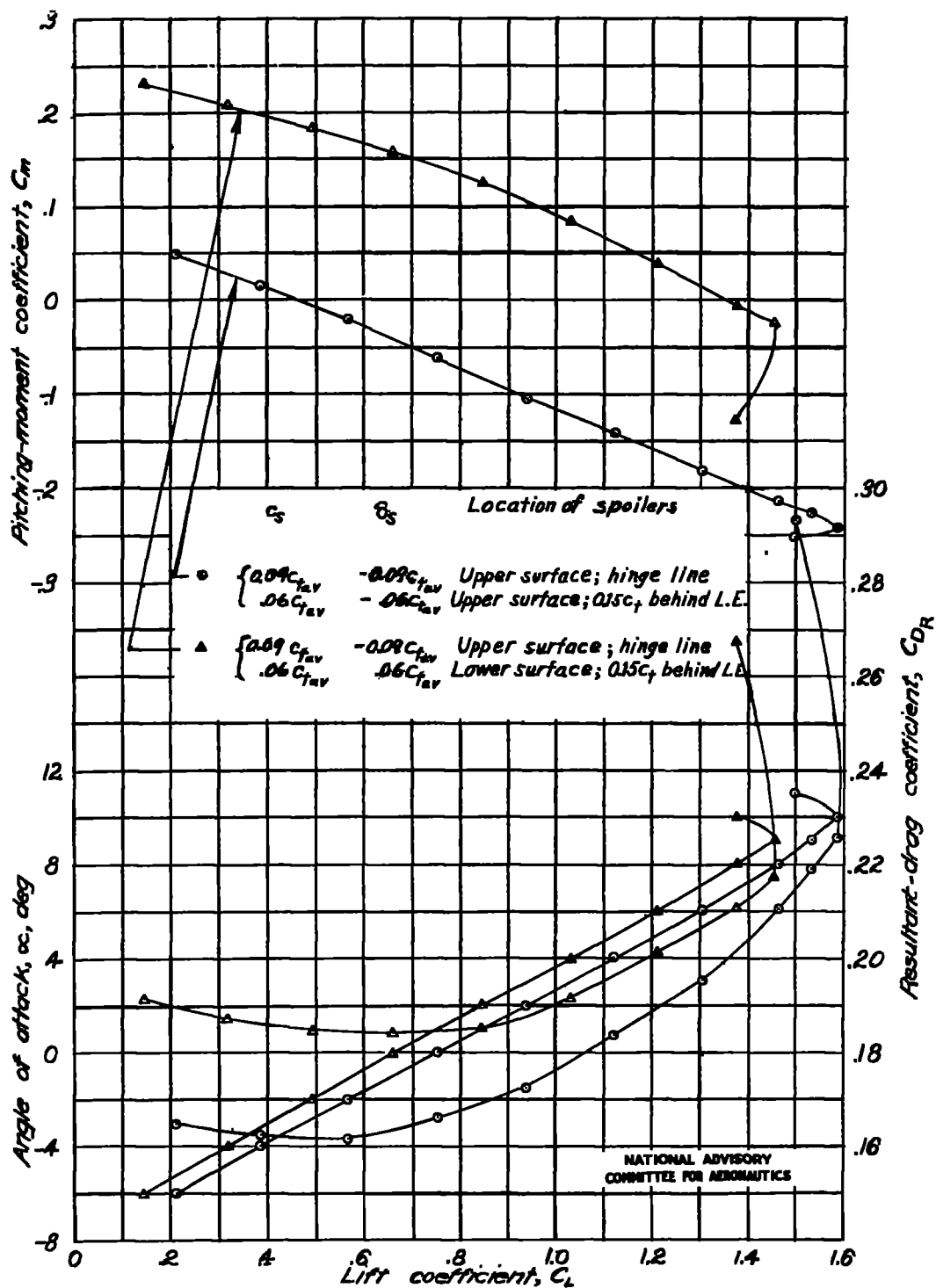


Figure 30.-Effect of spoiler combinations on aerodynamic characteristics of model A near ground board. $\delta_f = 45^\circ$; $\delta_e = 0^\circ$.

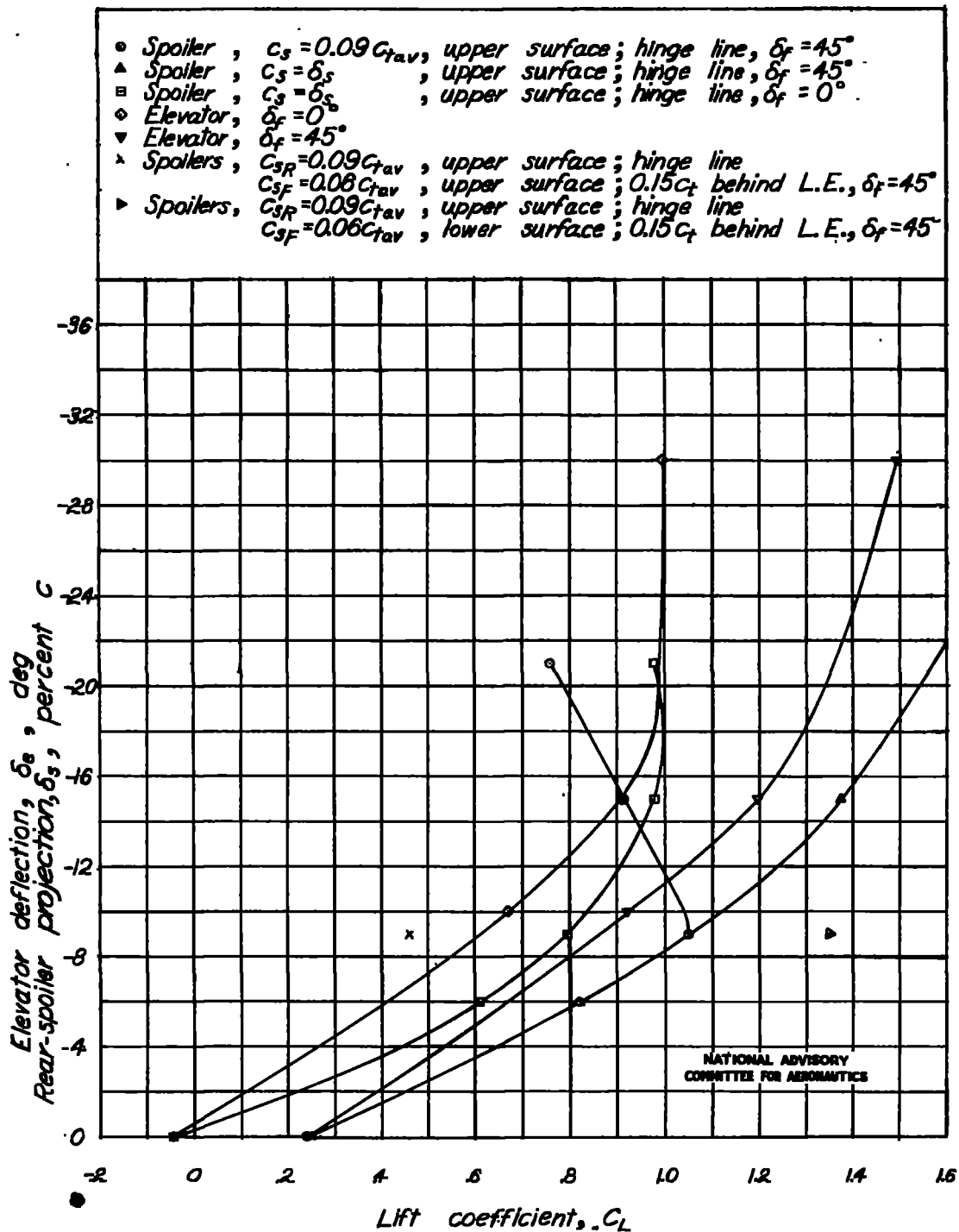
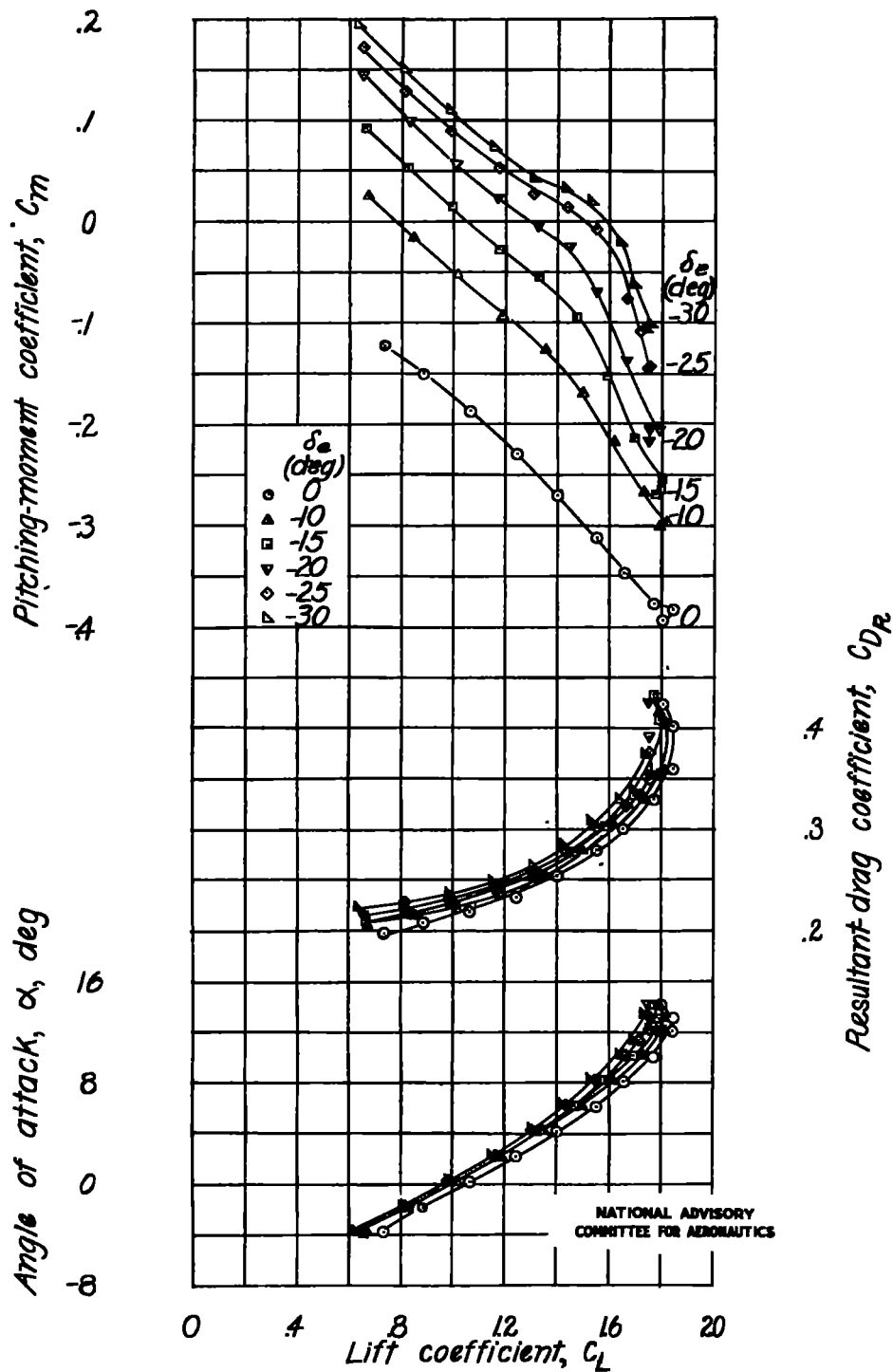
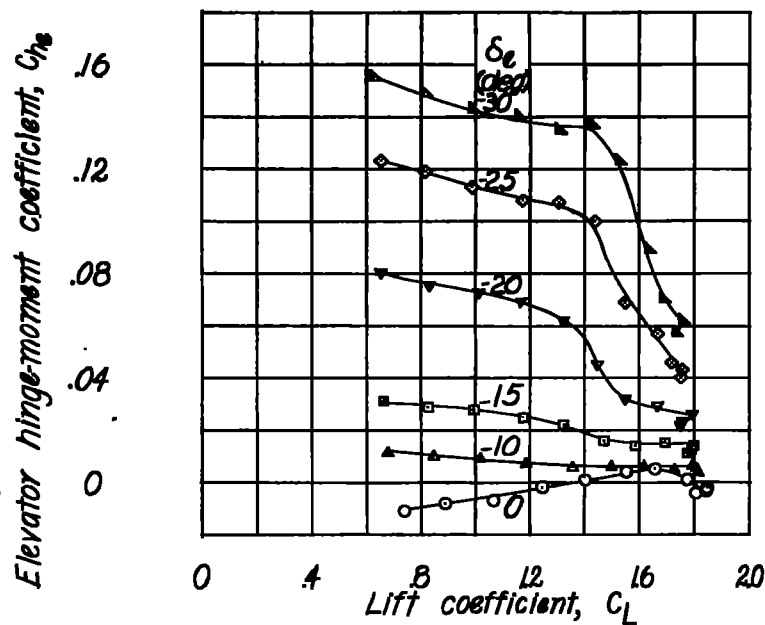


Figure 31.-Elevator deflections and spoiler projections required to trim model A near ground board.



(a) No spoiler.

Figure 32.-Effects of elevator deflection and spoiler projection on the aerodynamic characteristics of model B near ground. Propeller windmilling; landing configuration; horizontal tail in normal location; $i_t = 1.67^\circ$; center of gravity at $0.18c'$.



(a) No spoiler.

Figure 32.- Continued.

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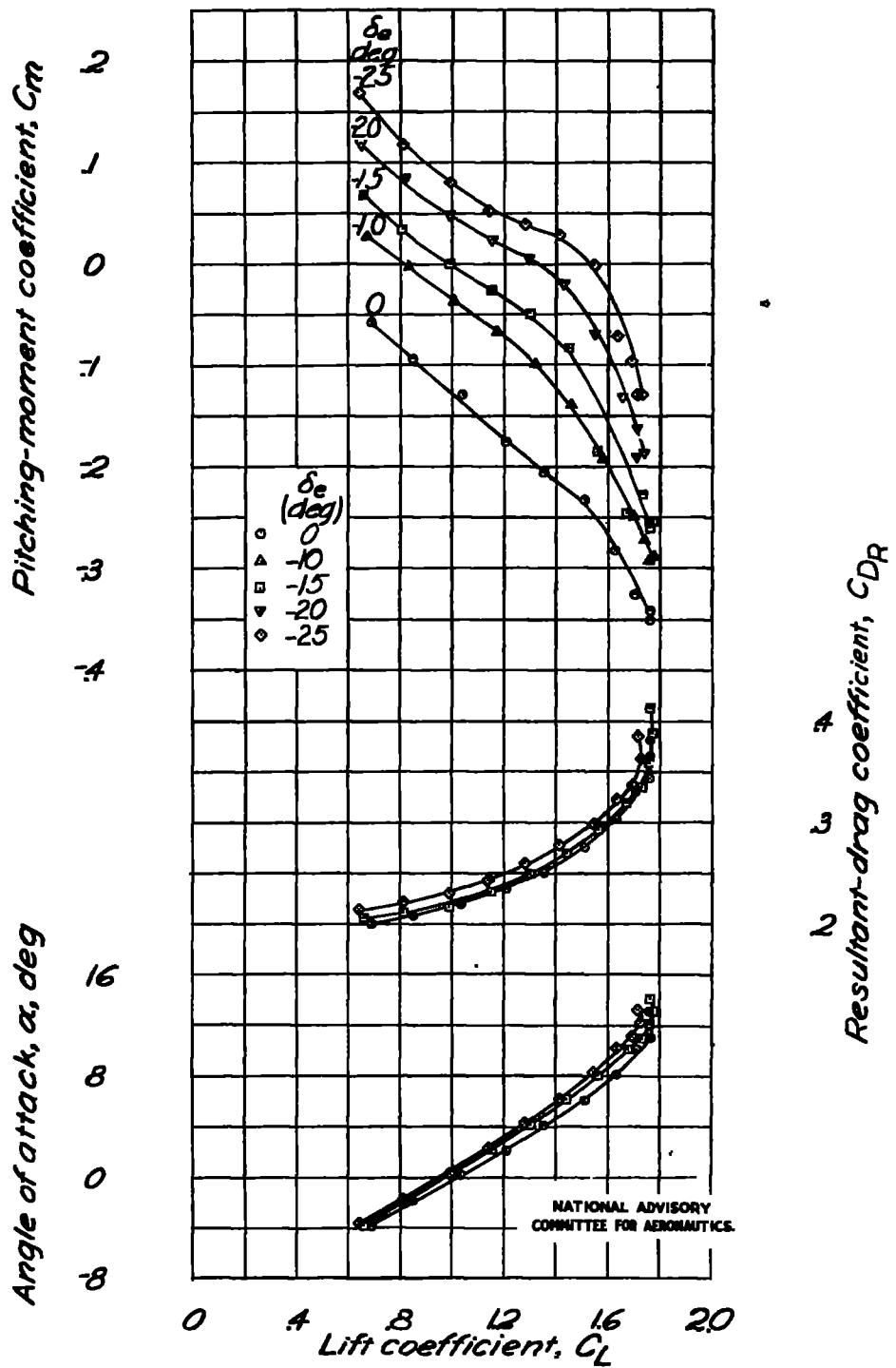
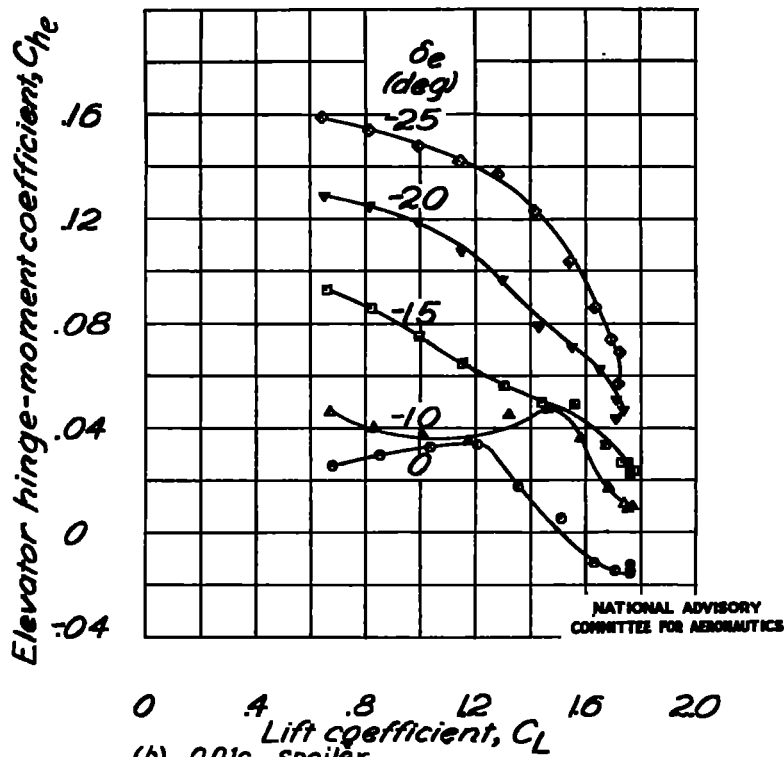
(b) 0.01 c_t spoiler.

Figure 32.- Continued.



(b) 0.01c, spoiler.
Figure 32.- Continued.

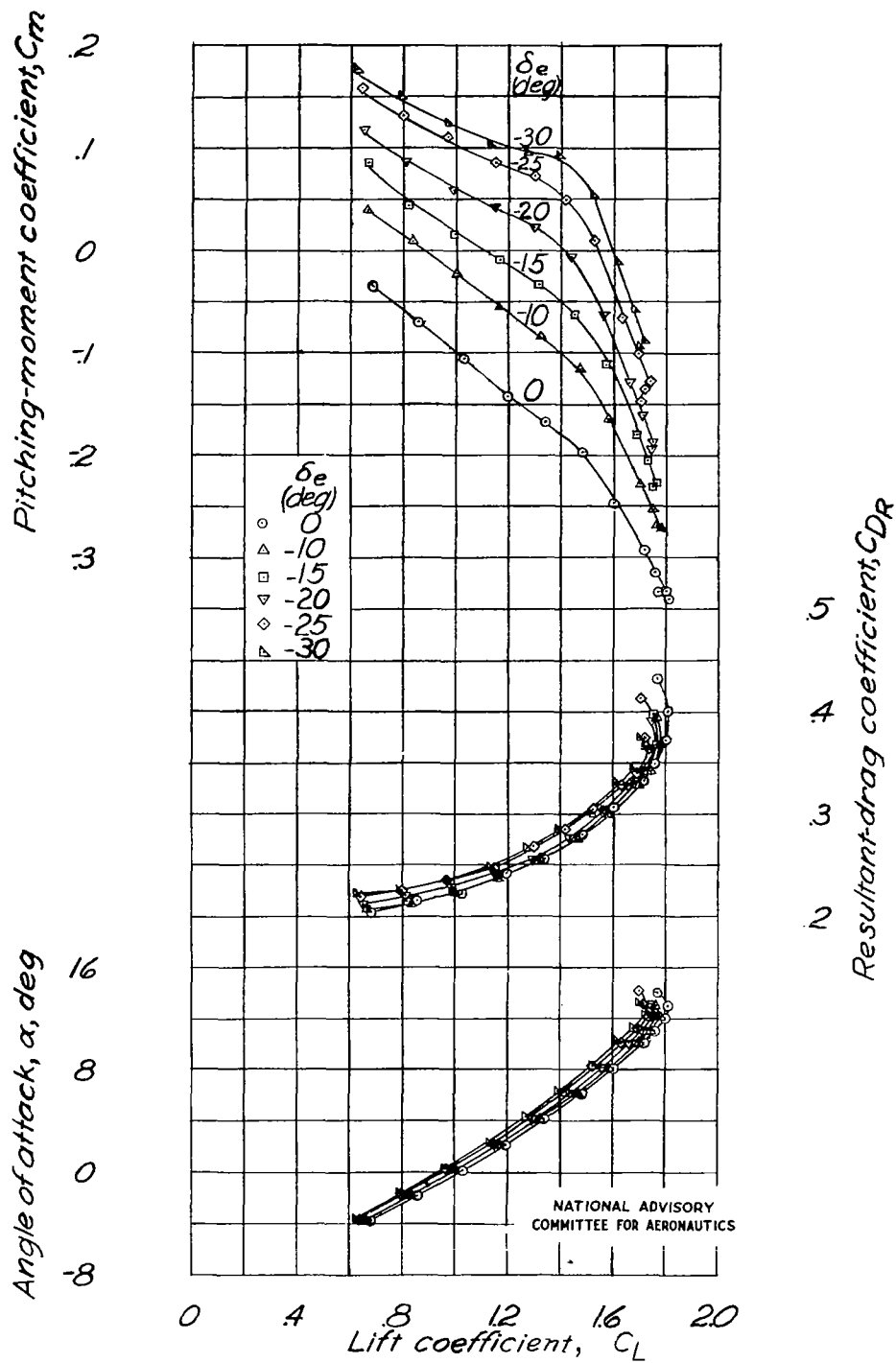
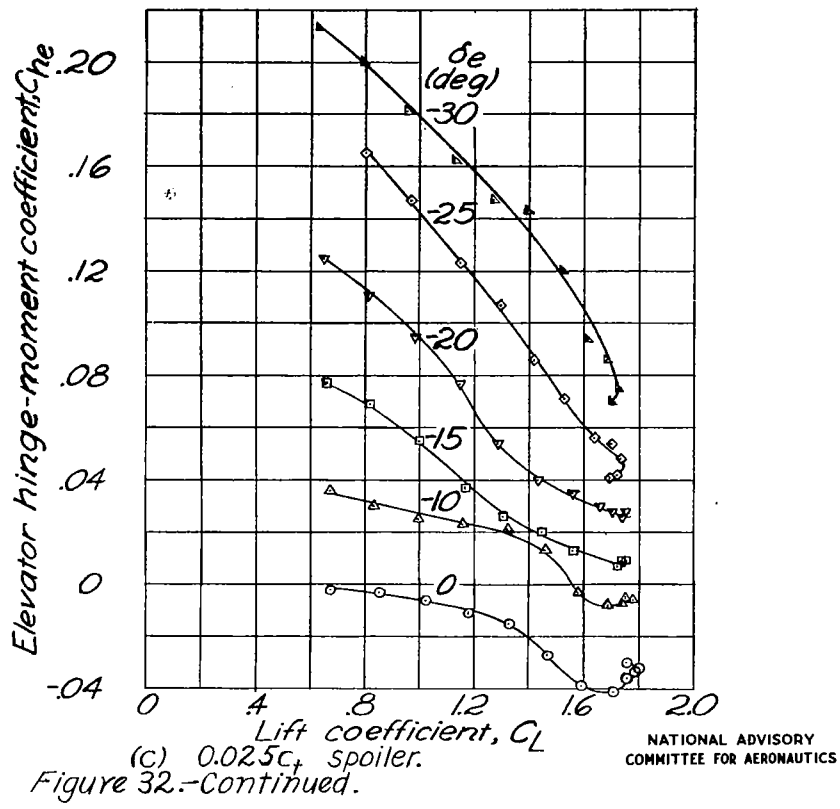
(c) 0.025 c_t spoiler.

Figure 32.- Continued.



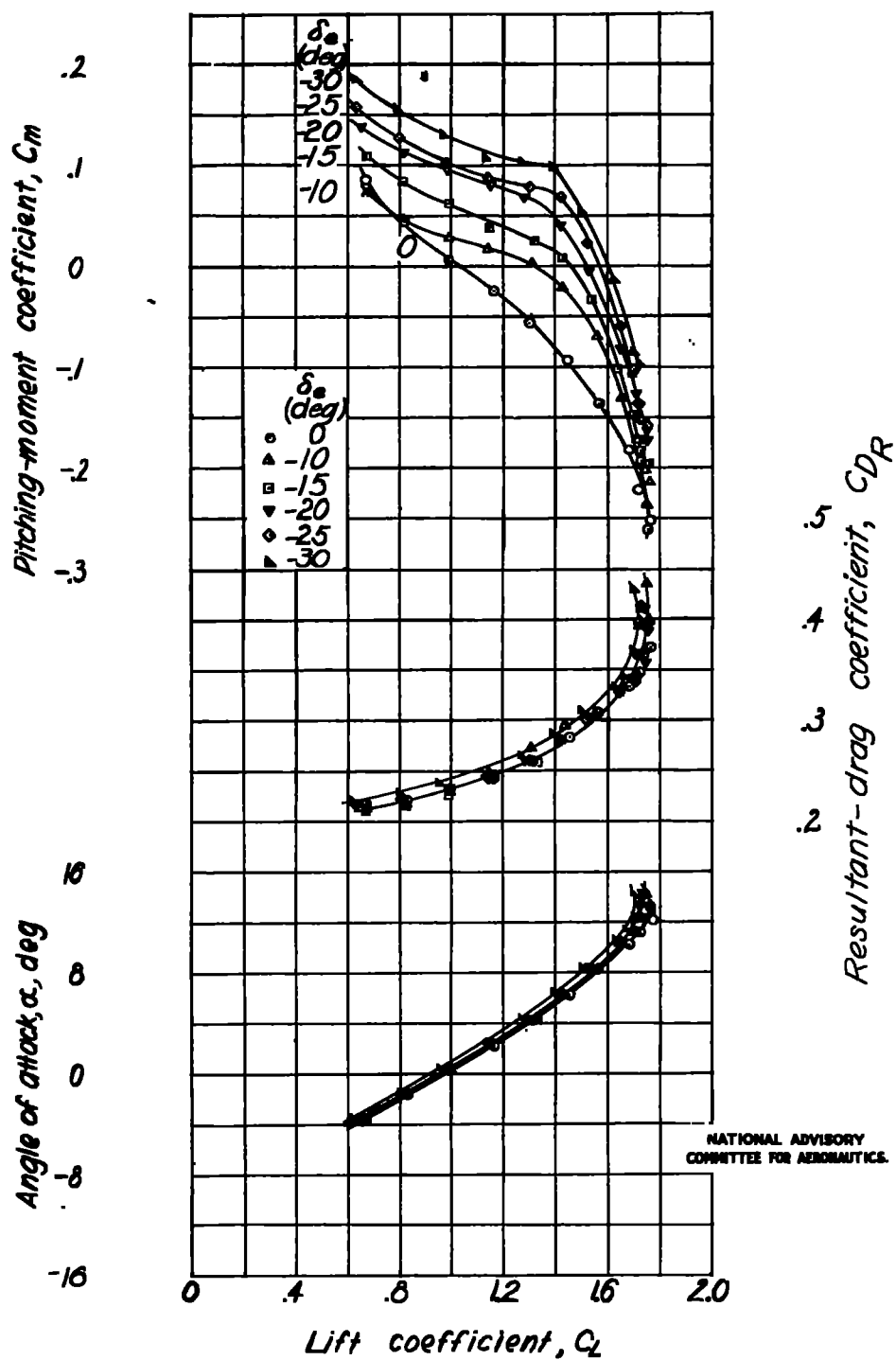
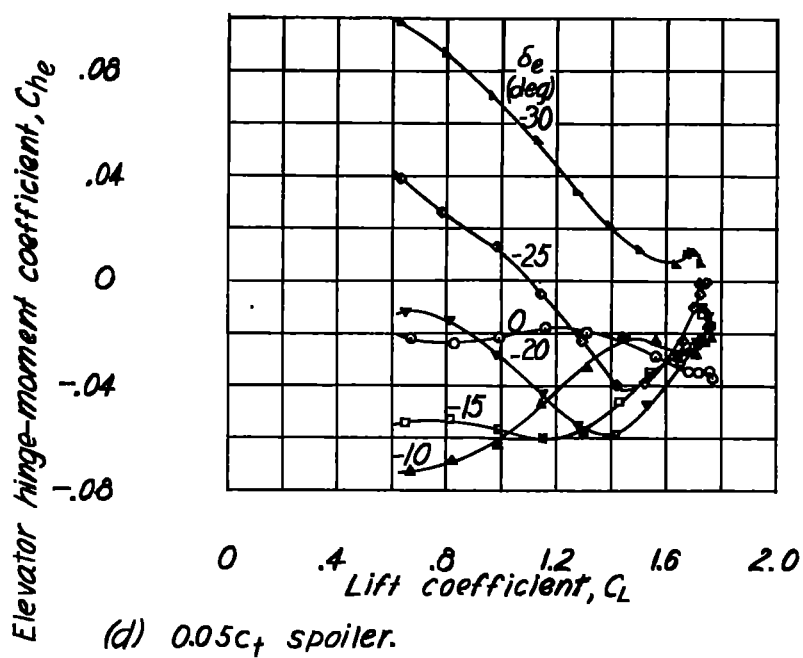
(d) $0.05c_t$ spoiler.

Figure 32.-Continued.



(d) $0.05c_t$ spoiler.

Figure 32.-Continued.

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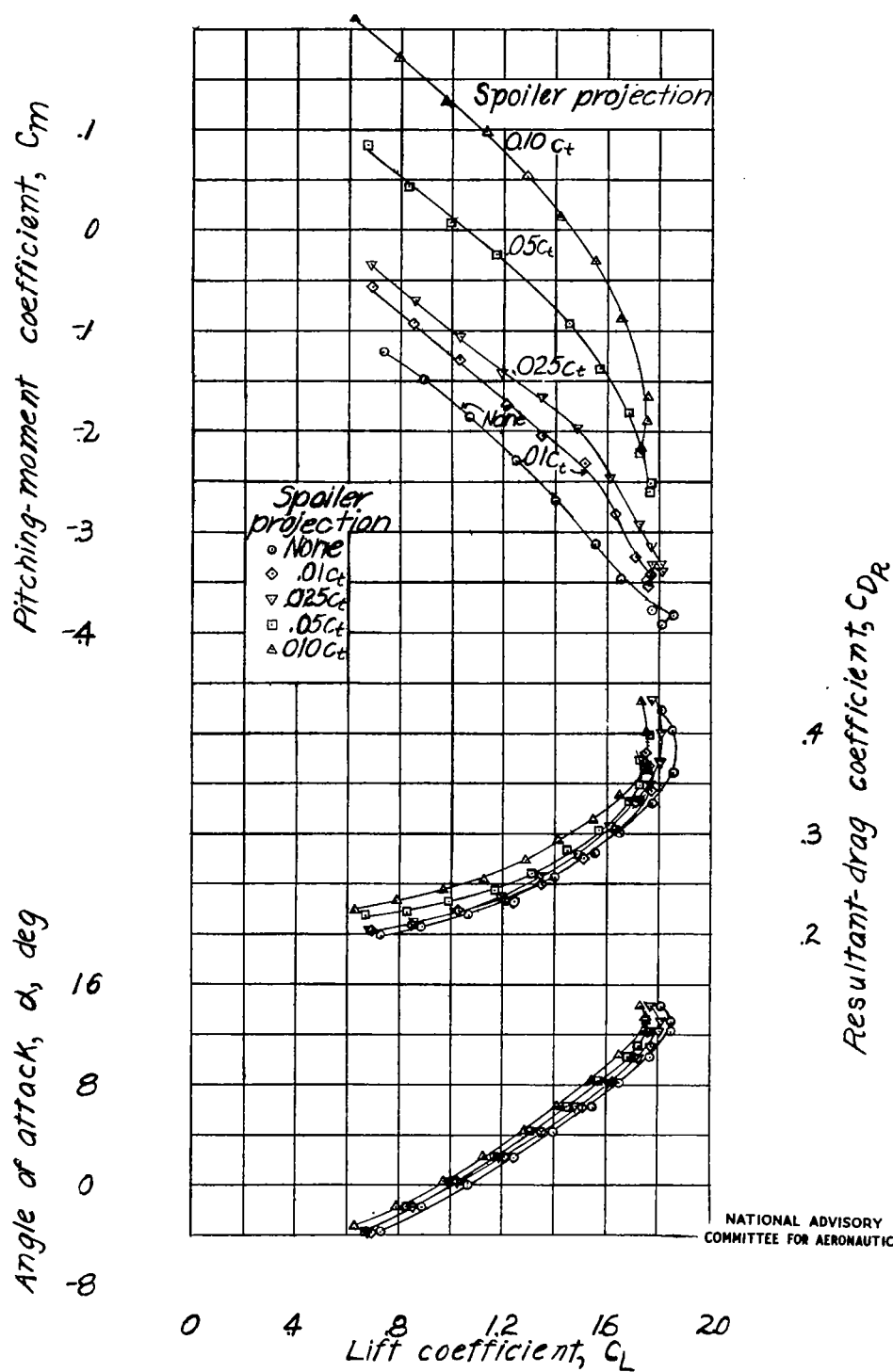


Figure 33.— Effect of spoiler projection on the aerodynamic characteristics of model B near ground. Propeller windmilling; landing configuration; horizontal tail in normal location; $i_t = 1.67^\circ$; $\delta_e = 0^\circ$; center of gravity at $0.18 C$.

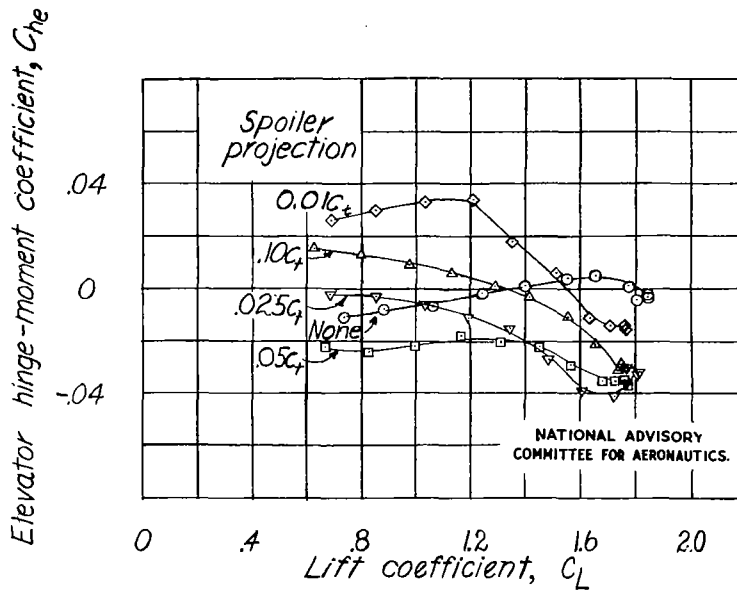
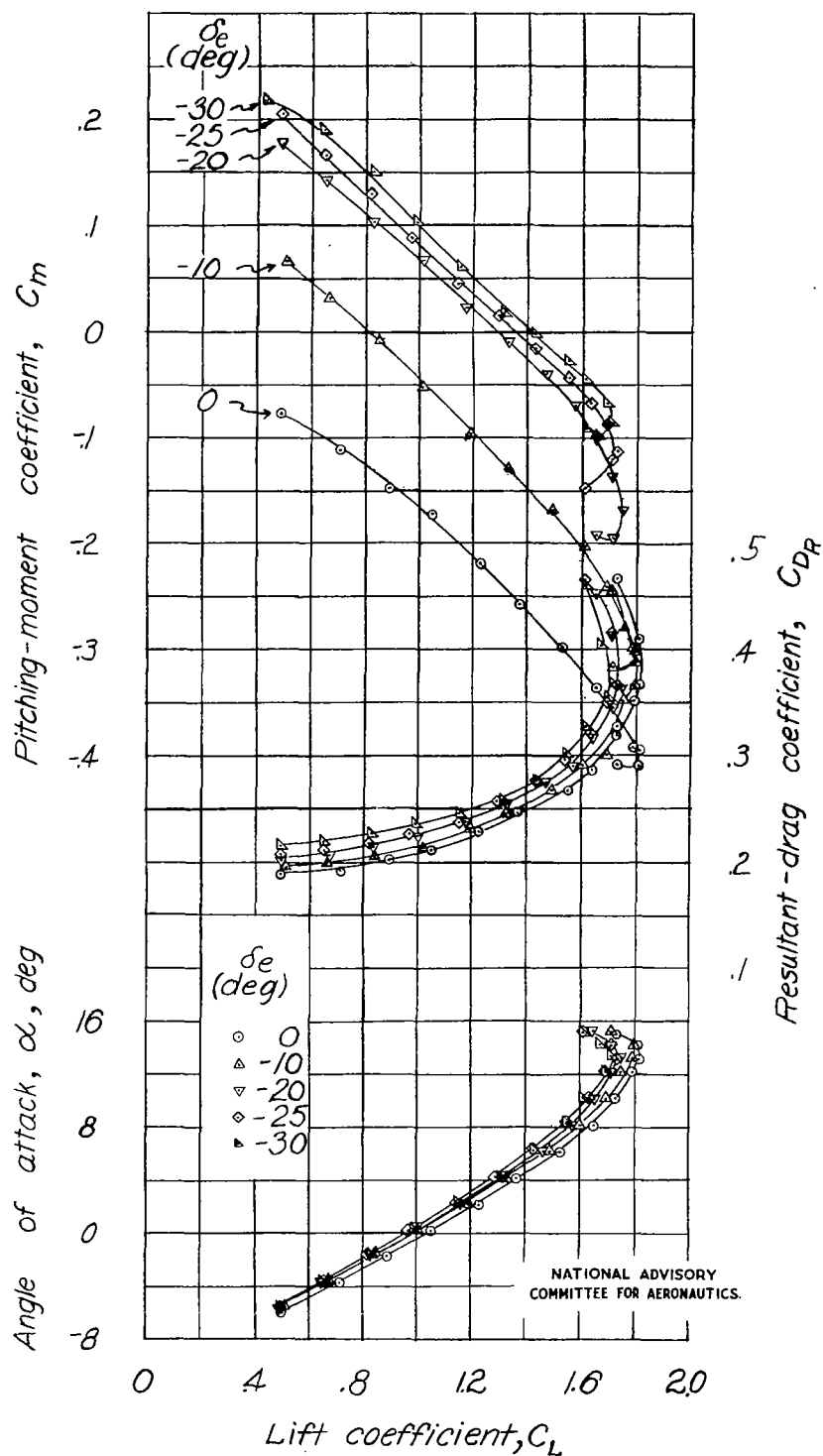
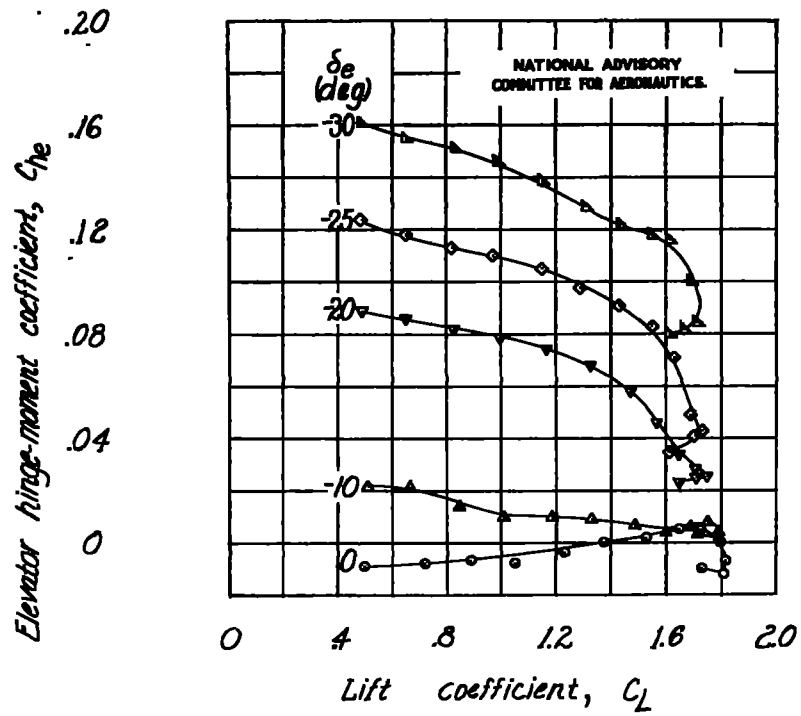


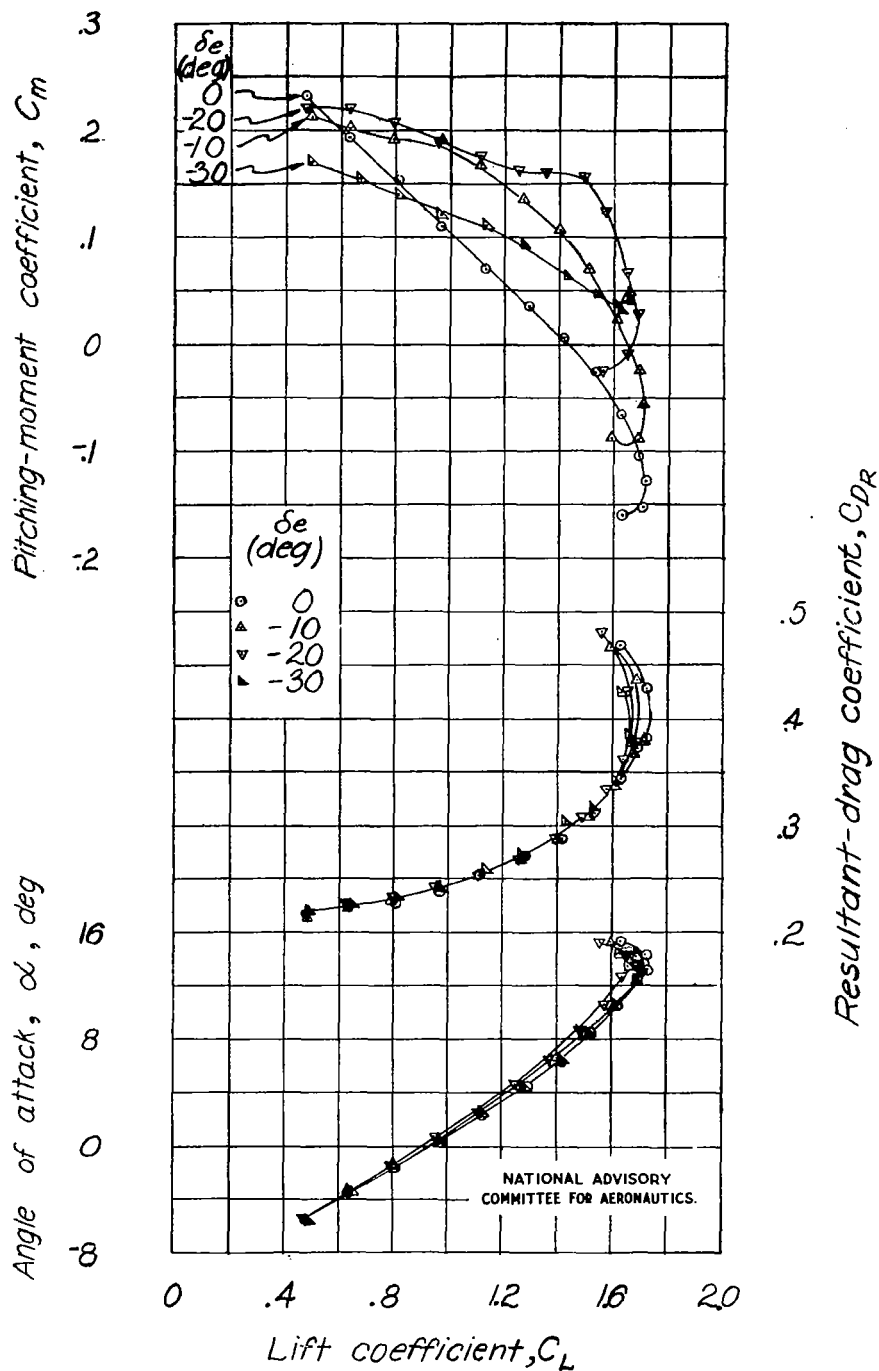
Figure 33.-Concluded.



(a) No spoiler ; $i_t = 1.00^\circ$.
 Figure 34.- Effect of elevator deflection on the aerodynamic characteristics of model B near ground. Propeller windmilling; landing configuration; horizontal tail raised 4.0 inches; center of gravity at $0.18 c'$.

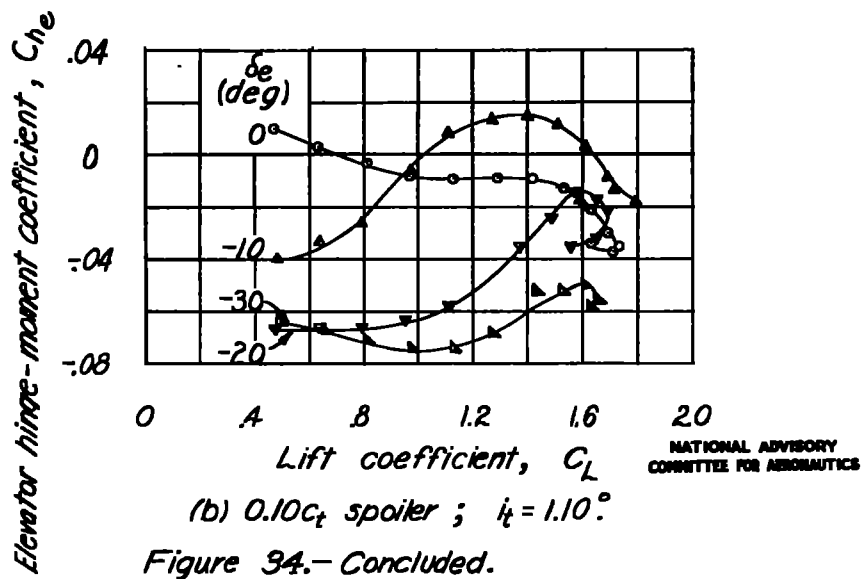


(a) No spoiler; $i_t = 1.00^\circ$.
Figure 34.-Continued.



(b) $0.10c_t$ spoiler; $i_t = 1.10^\circ$.

Figure 34.- Continued.



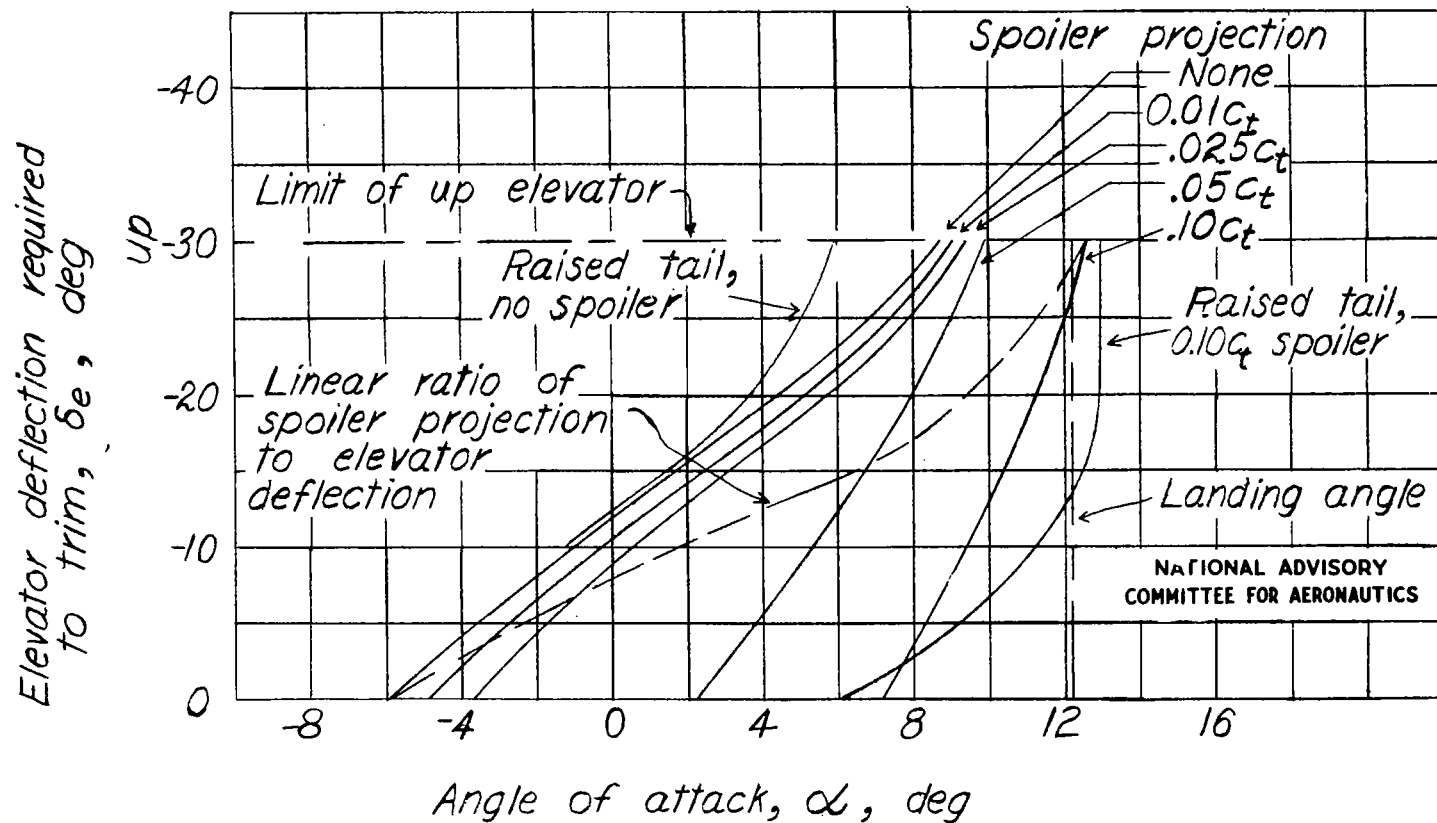


Figure 35.- Elevator deflection required to trim model B near ground. Propeller windmilling; landing configuration; $i_t = -1.42^\circ$; forward center of gravity at 14.2 percent c' .

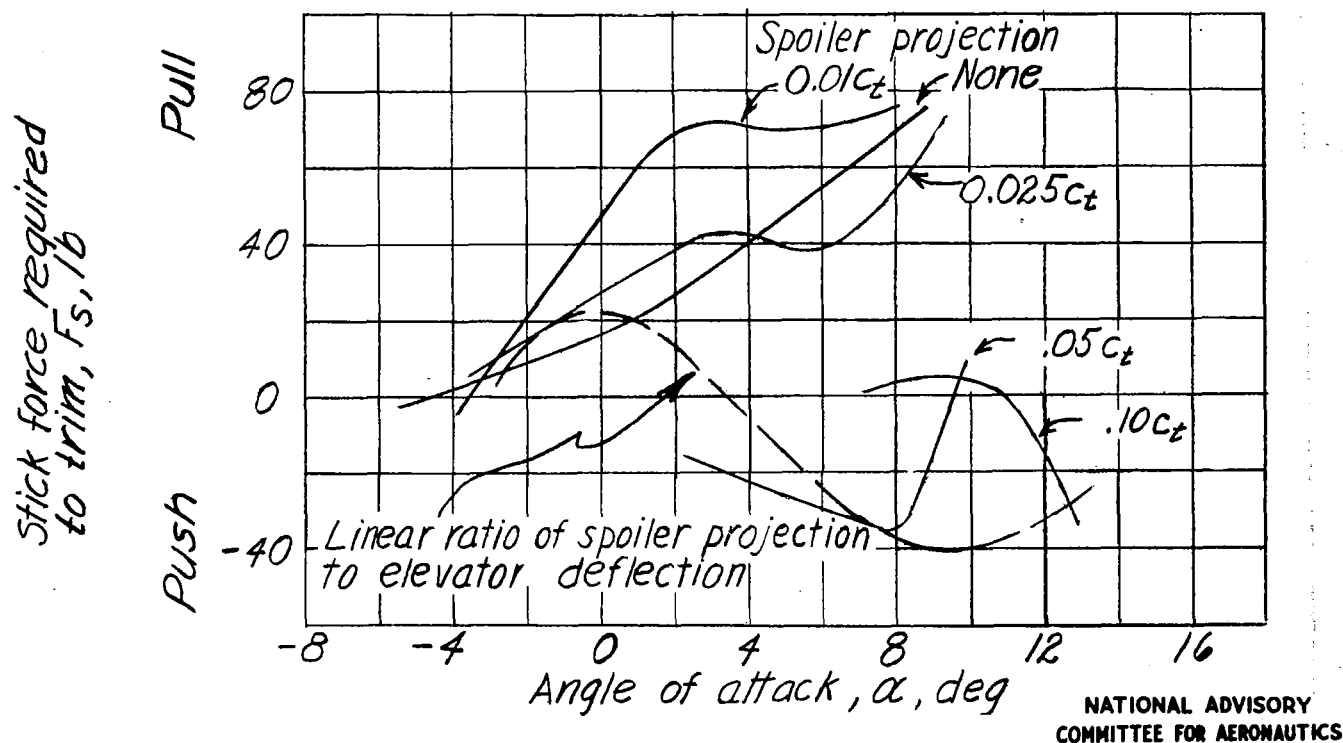


Figure 36.- Effect of spoiler projection on stick force required to trim model B near ground. Propeller windmilling; landing configuration; horizontal tail in normal location; $i_t = -1.42^\circ$; forward center of gravity at 14.2 percent c' .

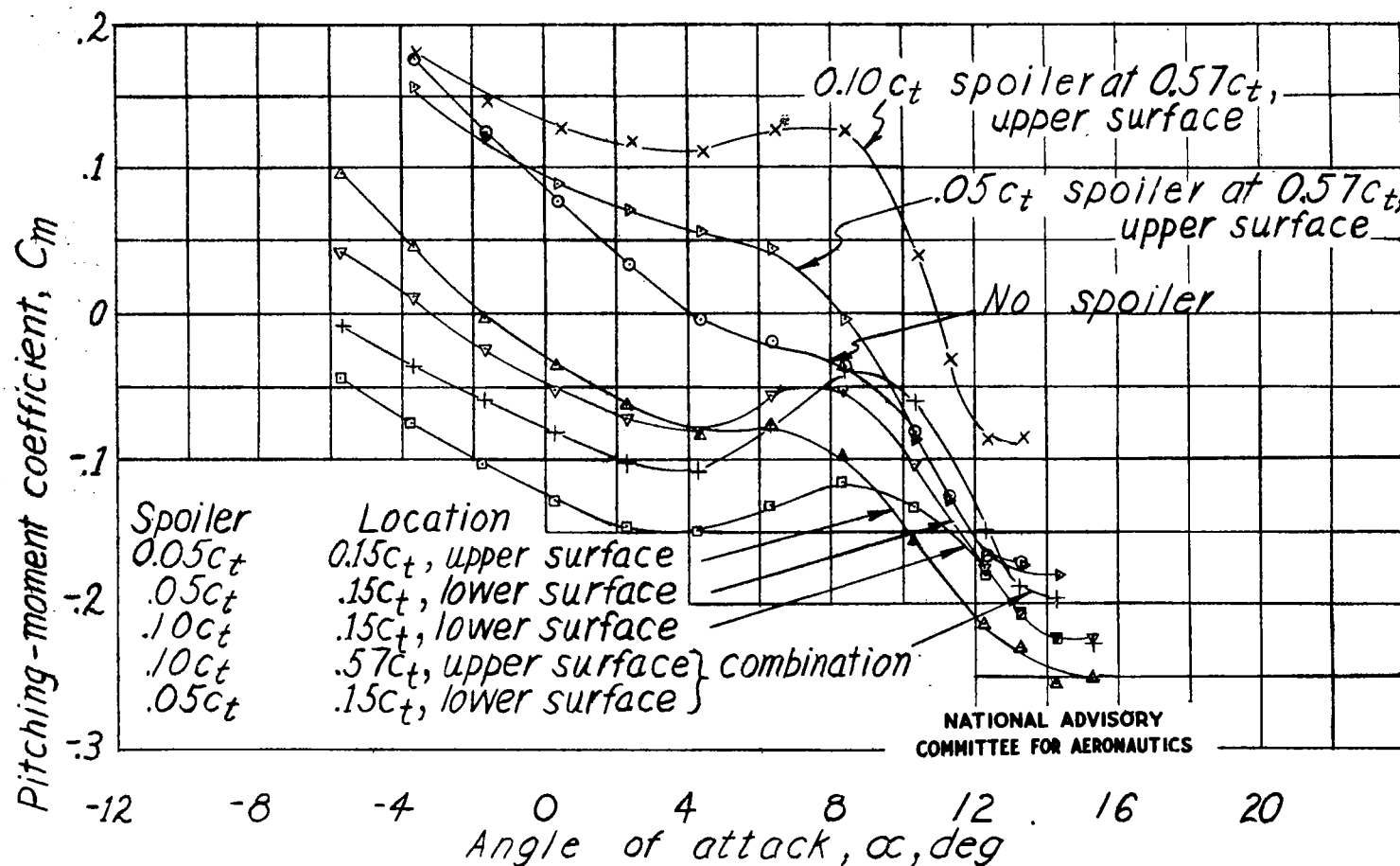


Figure 37.- Effect of spoiler height and location on the pitching-moment coefficient of model B near ground. Propeller windmilling; landing configuration; horizontal tail in normal location; $i_t = 1.00^\circ$; $\delta_e = -30^\circ$ ($\delta_e = -25^\circ$ for 0.05c_t and 0.10c_t spoilers at 0.57c_t, upper surface); forward center of gravity at 14.2 percent c'.

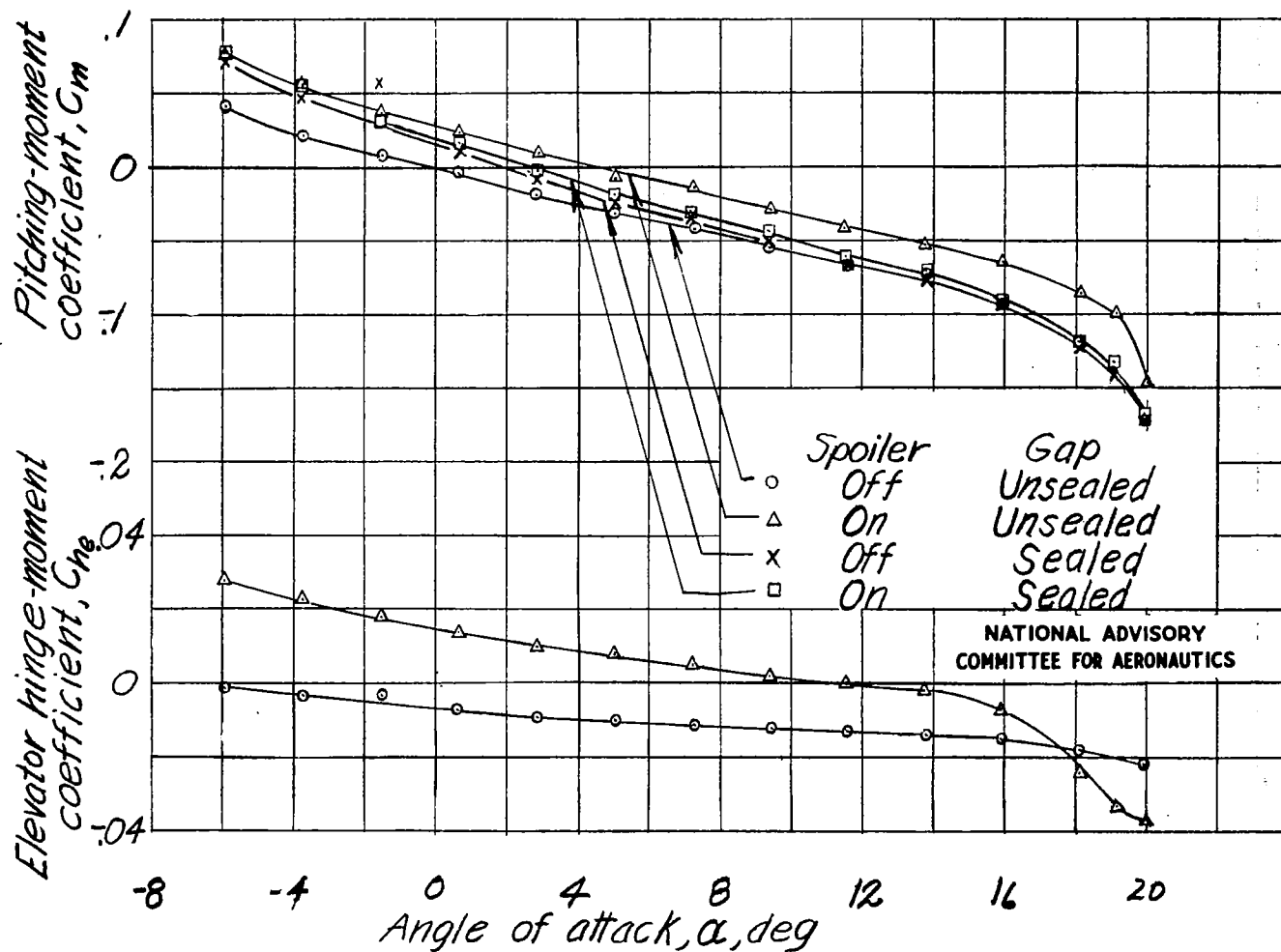


Figure 38.-Effect of $0.008c_t$ spoiler and elevator gap on the pitching-moment coefficient of a typical fighter-airplane model. $\delta_f = 40^\circ$; $\delta_e = \psi = 0^\circ$.

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